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A Review of Techniques for Incineration of Sewage Sludge with Solid Wastes

Roy F. Weston, Inc, West Chester, Pa

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This report discusses the state-of-the-art of co-incineration of municipal refuse and sewage sludge. European and American practice is described. Four co-incineration techniques are evaluated for thermodynamic and economic feasibility; pyrolysis, multiple hearth, direct drying, and indirect drying. Each process is compared with conventional separate incineration with respect to cost, practicality, and project environmental impact. Recommendations for specific demonstrations are made and EPA endorsement of co-incineration is proposed.

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This report has been reviewed by the Office of Research and Development, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our national environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

Development of safe and economical methods for disposing of the sludges produced from wastewater treatment operations is one of the most pressing environmental needs. This publication provides much needed information on the feasibility of utilizing an integrated approach to municipal sewage sludge and solid waste disposal.

Francis T. Mayo, Director
Municipal Environmental
Research Laboratory

ABSTRACT

This report discusses the state of the art of co-incineration of Municipal refuse and sewage sludge. European and American practice is described. Four co-incineration techniques are evaluated for thermodynamic and economic feasibility: Pyrolysis, Multiple-Hearth, Direct Drying and Indirect Drying.

This report was submitted in fulfillment of Contract No. 68-03-0475 by Roy F. Weston, Inc. under the sponsorship of the U.S. Environmental Protection Agency. Work began 4 June 1974 and was completed as of 5 September 1976.

CONTENTS

Foreword iii
Abstract iv
Figures. vii
Tables ix

I Introduction. 1
    Purpose and Scope. 1
    Background 1
    Refuse Incinerators. 2
    Sludge Incinerators. 4
    References 4
II Conclusions 7
    General. 7
    Historical 7
    Technical. 8
    Environmental. 9
    Economic 9
III Recommendations 11
    Technical Development. 11
    Policy 11
IV Co-Incineration -- The State of the Art 12
    Information Sources. 12
    Overview of Applicable Techniques. 13
    Discussion of Principal Co-Incineration Techniques 13
    References 37
V Feasibility Study 41
    Approach to Evaluation 41
    Direct-Drying Co-Incineration. 45
    Indirect-Drying Co-Incineration. 55
    Multiple-Hearth Co-Incineration. 68
    Pyrolysis Co-Incineration. 76
VI Air Pollution Aspects 89
    Characteristics of Emissions 89
    Emission Regulations 90
    Control Options -- MSS or MMR Systems. 91
    Impact of Co-Incineration on Emissions 93
    Controls Required for Co-Incineration. 95
    Final Considerations 95
    References 95
VII Economic Considerations 98
    Background 98
    Basic Cost Calculations. 101
    Analysis of Co-Incineration Costs. 102

CONTENTS
continued

VIII Circumstances Having Impact on Feasibility. 119
  Geography. 119
  Local Political Situations 120
  Cooperation between Public Agencies. 121
  Public- and Private-Sector Factors 122
  Government Funding 122
  Relative Acuteness of MSS or MMR Disposal Problems 123
  Local Cost Factors 124
  Auxiliary Fuels. 124

Appendices

A. Annotited bibliography. 125
B. Plant visits. 164
C. Generation and handling of wastewater treatment sludges 195
D. Refuse. 212

FIGURES

Number Page

1 Continuous-feed incinerator. 3

2 Multiple-hearth sludge incinerator 5

3 Fluid-bed sludge incinerator 6

4 Direct dryer co-incineration -- schematic flow sheet 46

5 Direct dryer co-incineration gas temperature (equivalent population). 50

6 Direct dryer co-incineration gas temperature (20% excess sludge). 52

7 Indirect dryer co-incineration -- schematic flow sheet 56

8 Indirect dryer co-incineration gas temperature (equivalent population). 61

9 Indirect dryer co-incineration gas temperature (20% excess sludge). 63

10 Heat-transfer coefficient for sludge drying. 65

11 Multiple-hearth co-incineration -- schematic flow sheet. 68

12 Multiple-hearth co-incineration gas temperature (equivalent population). 70

13 Multiple-hearth co-incineration gas temperature (20% excess sludge). 72

14 Multiple-hearth co-incineration using incinerator flue gas -- schematic flow sheet 75

15 Pyrolysis co-incineration -- schematic flow sheet. 77

16 Pyrolysis (equivalent population). 82

17 Pyrolysis feasibility -- 120% equivalent sludge. 84

FIGURES
continued

Number Page

18 Pyrolysis co-incineration with direct sludge pre-drying -- process flow sheet. 86

19 Pyrolysis co-incineration with indirect pre-drying -- process flow sheet. 87

B-1 Water treatment and incinerator flow sheet, Ansonia, Connecticut. 167

B-2 Longitudinal section through incinerators, Ansonia, Connecticut. 168

B-3 Flow sheet of sewage sludge and refuse incinerating plant, Dieppe, France. 172

B-4 Cross-section of Von Roll Evaporator, Dieppe, France. 173

B-5 Refuse incinerator at Dordrecht, Netherlands. 176

B-6 Flow sheet of combustible waste disposal system, Eastman Kodak Company 178

B-7 Flow sheet of Franklin (Ohio) environmental control complex 182

B-8 Water treatment incinerator flow sheet: Holyoke, Massachussetts 185

C-1 Wastewater treatment processes: substitution and sequence diagram. 198

C-2 Alternative sludge handling processes and systems 200

D-1 Refuse heating value as received. 223

TABLES

Number Page

1 Applications of MMR/MSS Co-Incineration Techniques. 14

2 Status Summary of Co-Incineration 19

3 Refuse and Sludge Composition 44

4 Input and Output of Analysis of Direct Dryer Co-Incineration Alternative by INCIN Program -- Equivalent Sludge/Refuse Production. 49

5 Input and Output of Analysis of Direct Dryer Co-Incineration Alternative by INCIN Program -- Sludge/Refuse Rates at 120 Percent of Equivalent Value 51

6 Input and Output of Analysis of Indirect Dryer Co-Incineration Alternative by INCIN Program -- Equivalent Sludge/Refuse Production. 60

7 Input and Output of Analysis of Indirect Dryer Co-Incineration Alternative by INCIN Program -- Sludge/Refuse Ratio at 120 Percent of Equivalent Value 62

8 Input and Output of Analysis of Multiple Hearth Co-Incineration Alternative by INCIN Program -- Equivalent Sludge/Refuse Production. 69

9 Input and Output of Analysis of Multiple Hearth Co-Incineration Alternative by INCIN Program -- Sludge/Refuse Ratio at 120 Percent of Equivalent Value 71

10 Input and Output of Analysis of Pyrolysis Co-Incineration Alternative by INCIN Program -- Equivalent Sludge/Refuse Production. 81

11 Input and Output of Pyrolysis Co-Incineration Alternative by INCIN Program -- Sludge/Refuse Ratio at 120 Percent of Equivalent Value. 83

12 Estimated Air Pollutant Emissions from Refuse, Sludge and Combined Incineration 96

TABLES
continued

Number Page

13 Construction Cost -- Modern Refuse Incinerator. 103

14 Total Facility Capital Cost -- Modern Refuse Incinerator. 103

15 Operating Cost -- Modern Refuse Incinerator 104

16 Construction Cost -- Multiple-Hearth Sludge Incinerator 104

17 Total Facility Capital Cost -- Multiple-Hearth Sludge Incineration. 105

18 Operating Cost -- Multiple-Hearth Incinerator 105

19 Construction Cost -- Co-Incineration/Rotary Sludge Dryer. 106

20 Total Facility Capital Cost -- Co-Incineration/Rotary Sludge Dryer. 106

21 Operating Cost -- Co-Incineration/Rotary Sludge Dryer 107

22 Construction Cost -- Co-Incineration/Indirect Sludge Dryer. 107

23 Total Facility Capital Cost -- Co-Incineration/Indirect Sludge Dryer. 108

24 Operating Cost -- Co-Incineration/Indirect Sludge Dryer 108

25 Construction Cost -- Co-Incineration/Multiple Hearth Furnace. . . . 109

26 Total Facility Capital Cost -- Co-Incineration/Multiple Hearth Furnace. 109

27 Operating Cost -- Co-Incineration/Multiple Hearth Furnace 110

28 Construction Cost -- Co-Incineration/Pyrolysis. 110

29 Total Facility Capital Cost -- Co-Incineration/Pyrolysis. 111

30 Operating Cost -- Co-Incineration/Pyrolysis 111

31 Summary of Co-Incineration Cost Analysis. 112

32 Manpower and Utility Summary. 115

33 1985 Co-Incineration Cost Analysis. 118

TABLES
continued

Number | Page

C-1 Typical Composition of Domestic Sewage. 197

C-2 Typical Air Flotation Design Parameters 203

C-3 Air Flotation Thickening Performance. 204

C-4 Typical Rotary Vacuum Filter Results for Sludge Conditioned with Organic Chemicals. 206

C-5 Typical Rotary Vacuum Filter Results for Polyelectrolyte-Conditioned Sludges 207

C-6 Estimated Chemical Conditioning Dosage for Vacuum Filtration 205

C-7 Typical Solid-Bowl Centrifuge Performance 208

C-8 Typical Filter Press Production Data. 209

C-9 Sludge Quantities 211

D-1 Projected Population and Annual Domestic Refuse Tonnage: Baltimore Region -- 1970 to 1990. 214

D-2 Domestic Solid Waste Composition Comparison -- Baltimore Region. 215

D-3 Annual Net Waste Generation -- Baltimore Region 217

D-4 Annual Net Generation of Special Wastes in the Baltimore Region. 218

D-5 Municipal Refuse Composition. 220

SECTION I

INTRODUCTION

PURPOSE AND SCOPE

This study was undertaken with the following objectives:

--To assess the state of the art of co-incineration, including demonstrated and experimental techniques, both foreign and domestic.

--To select four techniques for further study to identify the important design and operational parameters affecting feasibility.

--To establish the economic feasibility, for a selected area, of co-incineration compared to separate sludge and refuse incineration.

--To assess the environmental and political impact of co-incineration as a processing step for refuse and sludge before ultimate disposal of residues.

BACKGROUND

For the past 30 years, design engineers have been evaluating the technical feasibility of co-incineration of wastewater sludge and municipal refuse. A number of prototype co-incineration units reportedly have been successfully operated, including Holyoke, Massachusetts; Ansonia, Connecticut; Hershey, Pennsylvania; and Dordrecht, Netherlands. Others have been plagued with major operating problems which have resulted in discontinuation of the sludge portion of the feed, including Frederick, Maryland; Whitemarsh, Pennsylvania; Newburgh, New York; and Altrincham, England. A more complete list of co-incineration plants, demonstrations, experiments, and proposed facilities appears in Table 1.

There are other circumstances affecting the problem of sludge disposal. Shortage of land in the vicinity of large metropolitan areas has become a major concern in the selection of sites for future sanitary landfills. Furthermore, there continues to be considerable controversy surrounding ocean disposal of municipal sludges. The alternative, sludge incineration, is costly and makes demands on fossil-fuel supplies. The potential for savings in investment, operating expense, and energy consumption has focused renewed attention on the latest co-incineration technology and economics.

The number of co-incineration installations is small compared to the number of separate refuse and sludge incinerators. For example, in 1974 there were

140 incinerator plants (most with multiple furnaces) in the United States burning municipal refuse.[1] In 1970, there were over 230 sludge incinerators (municipal or industrial);[2] of this number, 175 were multiple-hearth units, and the remainder were fluidized-bed units. Known domestic sites where co-incineration was reportedly practiced totaled about a dozen at the start of the study.

REFUSE INCINERATORS

Domestic mixed municipal refuse (MMR) normally is an autogenous but highly variable fuel that can be difficult to burn under adverse climatic conditions when collection practice allows the refuse to become saturated with water from rain or snow.

Most of the MMR incinerators in the United States are grate-fired, refractory-wall furnaces that burn as-received refuse. Batch-feed furnaces are being phased out in favor of continuous-feed units. Excess air is used to control furnace temperature between 760° and 980°C (1,400° and 1,800°F). Figure 1 shows a cross-section of a continuous-feed incinerator, and typical design criteria appear in the next tabulation (Source: DeMarco *et al*.[3]):

Grate Loading	245-340 kg/sq m/hr (50-70 lb/sq ft/hr)
Grate Heat Release Rate	815,000 kg-cal/sq m/hr (300,000 Btu/sq ft/hr)
Furnace Heat Release Rate	112,500-225,000 kg cal/cu m/hr (12,500-25,000 Btu/cu ft/hr)
Excess Air	150-200 percent
Furnace Exhaust Gas Temperatures	760-980°C (1,400-1,800°F)

Grate-fired, steam-generating incinerators are very popular in Europe and are becoming increasingly popular in the United States and Canada. With a boiler-incinerator, the boiler surfaces remove sufficient heat from the furnace gases that the excess air can be cut back to only 50 to 100 percent.

Typical grate-fired incinerators burn as-received refuse, and no refuse preparation is necessary unless bulky wastes are to be processed. Other incinerators, however, burn shredded refuse, which does require preparation of the refuse.

The steam-generating incinerator in Hamilton, Ontario, Canada is designed to burn shredded refuse in a spreader-stoker incinerator.[4] Another approach is to burn shredded and cleaned refuse in suspension in a utility boiler,[5] the shredded refuse replacing a portion of the fossil fuel normally burned in the furnace.

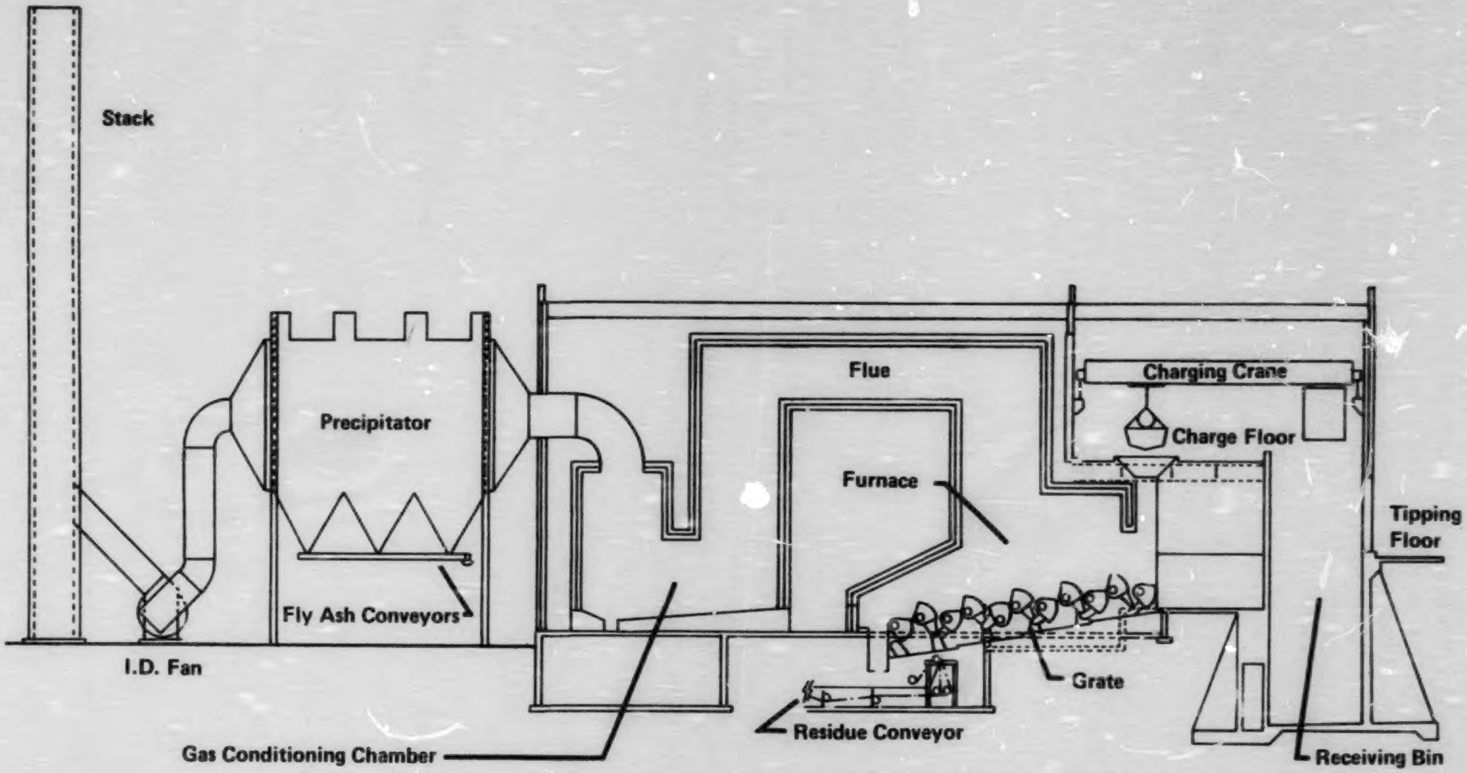
Stack
Precipitator
Fly Ash Conveyors
I.D. Fan
Gas Conditioning Chamber
Flue
Furnace
Residue Conveyor
Grate
Charging Crane
Charge Floor
Tipping
Floor
Receiving Bin

Figure 1. Continuous-Feed Incinerator.

In addition, several manufacturers are developing and marketing proprietary systems. One shaft furnace (Torrax)[6] is being marketed; another shaft furnace (Purox) is undergoing developmental testing;[7] and a 900 metric ton/day (1,000 tpd) rotary kiln system (Landgard) has been installed in Baltimore, Maryland.[8] There are others in various stages of development.

SLUDGE INCINERATORS

Simple gravity thickening, vacuum filtration, centrifugation, and pressure filtration have been and are being used to dewater Municipal Sewage Sludge (MSS) before incineration. Even with this preparation, the sludge is still generally not autogenous. Dewatered primary treatment plant sludge requires little auxiliary fuel, since the sludge is readily dewatered and sludge solids have a significant heating value. Secondary sludges are dewatered with difficulty, producing a high-moisture sludge cake, containing solids of low heating value. The addition of large quantities of secondary sludge, resulting from improved wastewater treatment, will reduce the "combustibility" of the total sludge load, thereby increasing the auxiliary fuel requirement.

The three most popular sludge-incinerator systems are the multiple-hearth and fluid-bed furnaces and the flash-drying arrangement used in conjunction with a fossil-fuel or refuse-fired furnace. Figures 2 and 3 are sketches of the cross-sections of typical multiple-hearth and fluid-bed furnaces, respectively. All these systems require the use of an auxiliary fuel during operation to make up for the sludge's heat deficiency. Burd[9] and Balakrishnan[10] have reviewed sludge-incinerator practices and discuss the three systems mentioned, plus a number of others. More recently, EPA has published a technology transfer document[11] on sludge treatment and disposal.

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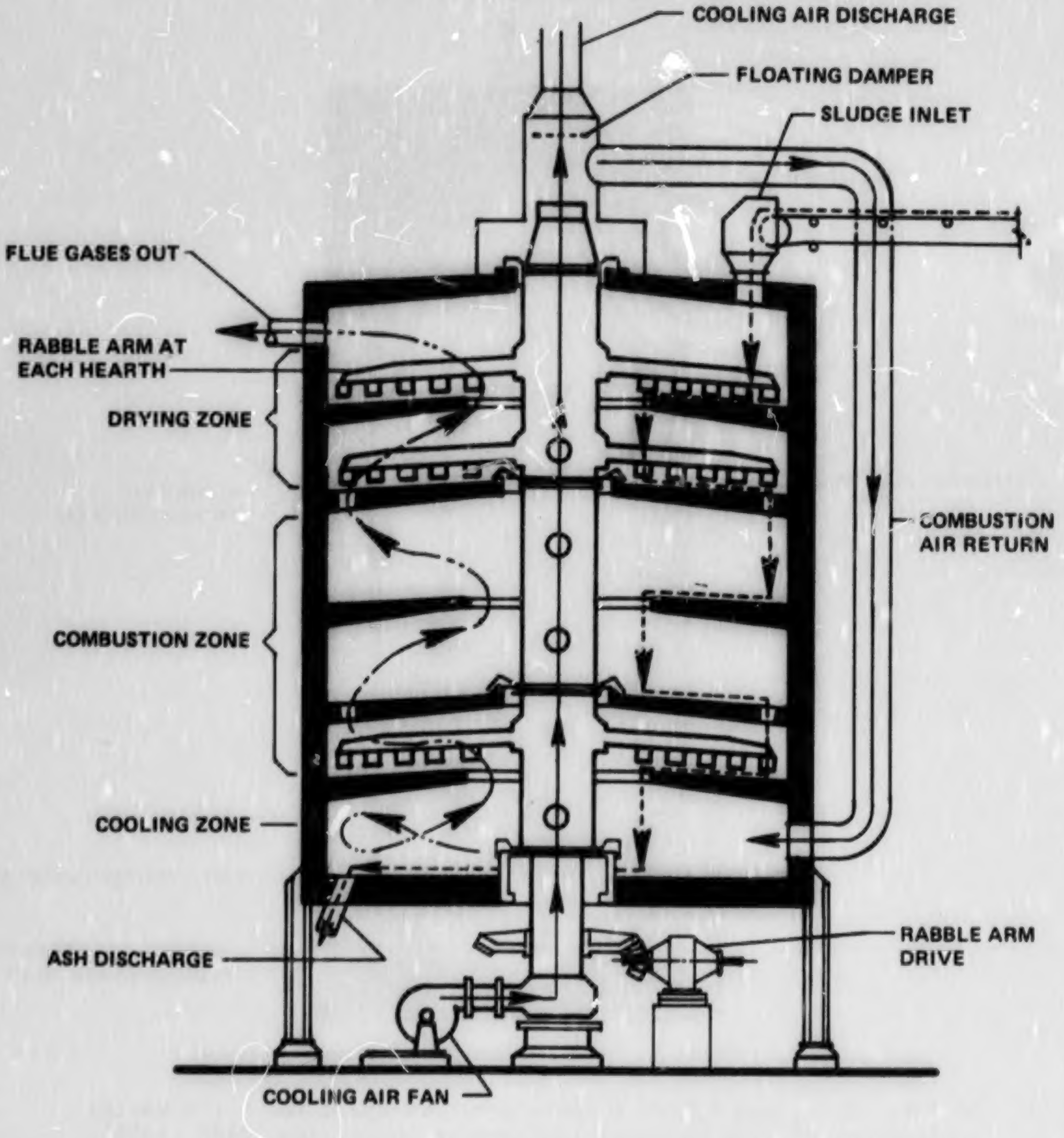
COOLING AIR DISCHARGE
FLOATING DAMPER
SLUDGE INLET
FLUE GASES OUT
RABBLE ARM AT EACH HEARTH
DRYING ZONE
COMBUSTION AIR RETURN
COMBUSTION ZONE
COOLING ZONE
ASH DISCHARGE
RABBLE ARM DRIVE
COOLING AIR FAN

Figure 2. Multiple-Hearth Sludge Incinerator.

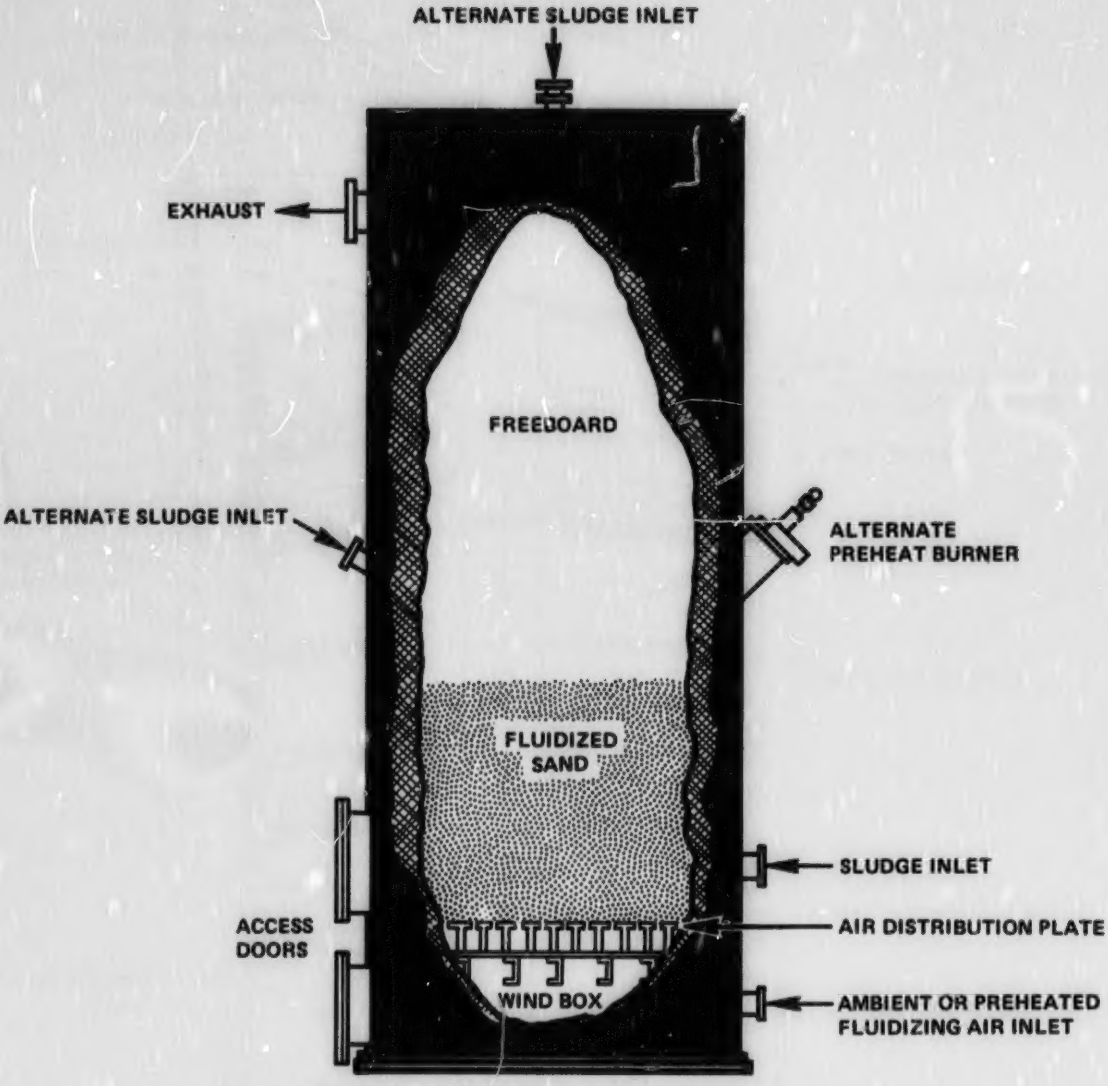
ALTERNATE SLUDGE INLET
EXHAUST
FREEBOARD
ALTERNATE SLUDGE INLET
ALTERNATE
PREHEAT BURNER
FLUIDIZED
SAND
SLUDGE INLET
ACCESS
DOORS
AIR DISTRIBUTION PLATE
WIND BOX
AMBIENT OR PREHEATED
FLUIDIZING AIR INLET

Figure 3. Fluid-Bed Sludge Incinerator.

8. Bielski, E.T., and A.C.J. Ellenberger. Landgard for Solid Wastes. Proceedings of 1974 National Incinerator Conference, ASME (1974).

9. Burd, R.S. A Study of Sludge Handling and Disposal. FWPCA (EPA) Publication WP-20-4, NTIS No. PB-179 514 (May 1968).

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11. Process Design Manual for Sludge Treatment and Disposal. Environmental Protection Agency 625.1-74-006 (October 1974).

SECTION II

CONCLUSIONS

GENERAL

1. Co-incineration is a viable technique for the disposal of municipal refuse and wastewater treatment plant sludge before ultimate disposal.

2. A co-incineration process using direct-contact pre-drying in a rotary dryer is the best developed technique, although co-incineration by indirect contact pre-drying, in multiple-hearth furnaces or by pyrolysis, is technically feasible.

3. Co-incineration by direct contact pre-drying in a rotary dryer offers the most attractive economics of the four techniques evaluated; however, all four co-incineration processes will result in lower total disposal cost than separate incineration of refuse and sludge.

4. Socio-political factors have been and will continue to be the greatest impediment to the widespread use of co-incineration.

5. The Environmental Protection Agency and other governmental agencies and authorities should act to encourage the use of co-incineration as a sludge and refuse pre-processing step to reduce the environmental, economic, and energy-usage impact of the total disposal system.

HISTORICAL

6. Co-incineration of refuse and sludge has not been widely practiced in the U.S. At present, there are only three municipal co-incineration plants in operation in this country.

7. Previous attempts at co-incineration in the U.S. have generally met with little success. With few exceptions, most U.S. co-incineration plants have been designed with sludge incineration retrofitted to existing refuse incinerators.

8. Ready availability of alternative solids-disposal methods has been the principal reason for the relative lack of U.S. interest in co-incineration to date. Landfill areas have been available at reasonable distances. Simple sludge incineration has been economical with plentiful supplies of low-cost fuels.

9. The organizational separation of those responsible for refuse disposal and those responsible for wastewater treatment and sludge disposal is another factor inhibiting the development of co-incineration.

10. Co-incineration experiences in Europe have been more widespread and more sucessful than in the U.S., indicating that interest in co-incineration is stimulated when land area becomes limited and fuel costs become high.

TECHNICAL

11. The following four co-incineration techniques appear most promising, and were selected for in-depth study:

    a. Direct-contact sludge pre-drying with heat provided by the co-incineration of refuse and dried sludge.

    b. Indirect-contact sludge pre-drying with heat provided by the co-incineration of refuse and dried sludge.

    c. Combined feed of sludge and refuse to a multiple-hearth incinerator.

    d. Combined feed of sludge and refuse to a pyrolysis furnace.

12. A heat and material balance for all four systems indicates that sufficient heat is available to co-incinerate refuse and dewatered sludge (20 percent solids) at rates consistent with those generated by equivalent population, i.e., the amount of solid waste and sludge produced per capita.

13. The two most significant variables affecting the co-incineration heat balance are furnace excess air and total moisture entering the co-incineration plant (i.e., moisture in refuse plus moisture in sludge).

14. All co-incineration techniques studied but pyrolysis could be designed and built with available equipment, engineering practices, and standards. The pyrolysis co-incineration technique is dependent on the development of new hardware, processes, or technologies.

15. The co-incineration technique involving direct-contact sludge pre-drying involves the lowest technical risk of any of the four techniques, and should be considered as in the same risk category as the design/construction of a refuse incinerator.

16. Co-incineration involving indirect-contact sludge pre-drying also represents a low-risk technology. Indirect sludge drying has been demonstrated in Europe. The only risk factor is the potential fouling of the heat-transfer surface with dry sludge or char. This co-incineration technique is useful where high-moisture sludge must be processed.

17. Multiple-hearth co-incineration is a medium-risk technique. Although plants have been operated in Europe, questions remain. The system requires a shredder to reliably produce a nominal 2.5 cm (1") refuse size. The

combustion of refuse alone in a multiple-hearth furnace has not been demonstrated. Multiple-hearth co-incineration does offer the lowest unit capacity, and is thus appropriate for small communities.

18. Co-incineration by pyrolysis must be regarded as a high-risk technology. Units operating on refuse alone have yet to be commercially demonstrated. This process does offer several potential advantages, including small size, potential for energy recovery, and flexibility in the sludge moisture which is acceptable.

19. The co-incineration plant site should be within pumping distance of the wastewater treatment plant. Storage, transportation, and odor control for thickened or dewatered sludge are impractical. Refuse is generally handled by truck already, and while additional mileage may be incurred, it is more desirable than transporting both sludge and refuse.

20. Because of the many factors involved in determining the advisability of co-incineration and in selecting the process, plant site, sludge dewatering equipment, and sludge-to-refuse ratio, a thorough study must be made case by case.

ENVIRONMENTAL

21. Volume and weight reductions for co-incineration will be approximately the same as for separate incineration of both materials. Unburned carbon levels in the residue should be lower for co-incineration in pyrolysis and multiple-hearth equipment than for incineration in conventional incinerators.

22. The adverse impact of co-incineration on air and water quality should be no greater than for separate incineration of sludge and refuse. Particulate air pollution control for co-incineration equipment has increased efficiency requirements over separate incineration facilities, but proven technology is available.

23. The impact of co-incineration on land use will be beneficial. Co-incineration provides a technically feasible and economically viable process for reducing the amount of waste requiring ultimate disposal, thereby providing an alternative to direct land disposal of unprocessed refuse and sludge.

ECONOMIC

24. Each of the four co-incineration techniques evaluated will have lower overall cost than separate incineration of sludge and refuse. The improved economics, however, will not bring the costs down to the level of land or ocean disposal.

25. In terms of capital investment, direct-pre-drying/co-incineration and indirect-pre-drying/co-incineration are lowest, followed by multiple-hearth and pyrolysis. Until recently, municipalities could obtain the capital for major facilities at attractive interest rates.

As the municipal bond market falters and interest rates climb, however, total capitalized cost will become a more significant factor.

26. With regard to operating cost, direct-pre-drying/co-incineration and indirect-pre-drying/co-incineration have the lowest estimated cost, followed by pyrolysis and multiple-hearth in that order.

27. Total annual cost (cost of owning and operating) is lower for any of the four co-incineration processes than for separate incineration of sludge and refuse. The direct-contact-dryer process would have the lowest total cost, 18 percent lower than separate incineration. The indirect-drying process would follow closely (17 percent), then pyrolysis (10 percent) and multiple hearth co-incineration (4 percent).

28. Economic advantages of co-incineration result primarily from reductions in manpower and auxiliary fuel costs.

29. Projection of costs indicates that co-incineration will be more economically attractive in 1985 than in 1975, because inflation is expected to have more impact on separate disposal than on combined disposal of sludge and refuse.

SECTION III

RECOMMENDATIONS

TECHNICAL DEVELOPMENT

1. Study the technical problems of indirect-drying co-incineration through demonstrations in existing boiler-incinerator systems. Particular problems include boiler corrosion and slagging in the tube banks and the effects of fouling on heat transfer rates and abrasion in the dryer.

2. Demonstrate multiple-hearth co-incineration, since this concept is a viable technology which has special applicability for smaller communities but which is not now used in the U.S. Include studies to minimize expense entailed in shredding the refuse and sludge.

3. Study the feasibility of mixing sludge with refuse ahead of shredding (for multiple-hearth systems). Such an approach would make use of the lubricating effect of sludge moisture (reducing shredder wear and power consumption), inhibit fires in the shredder, and bring about homogenization of sludge and refuse. Odor control would have to be considered.

4. Assess the performance, economics, and environmental impact of an operating co-incineration plant in the U.S. The Stamford, Connecticut plant appears to be a good candidate.

POLICY

5. Establish guidelines to clarify the dividing line between wastewater treatment and solid waste management (as it affects the availability of federal grants for 201 and 208 planning, facilities construction, etc.) in co-incineration situations.

6. Consider the development of a policy favorable to co-incineration by EPA (perhaps in conjunction with the Federal Energy Office).

7. Study and test alternative EPA policies which encourage the inter- and intra-jurisdictional cooperation usually needed for co-incineration systems to become politically feasible.

8. Actively participate (financial support and information exchange) with the European technical community now engaged in studies of co-incineration.

SECTION IV

CO-INCINERATION -- THE STATE OF THE ART

INFORMATION SOURCES

Information on co-incineration practices was acquired from review of patents and the technical literature, and from operator and vendor contacts, professional associations, and visits to selected installations in the United States and overseas. An annotated bibliography of published material is presented in Appendix A.

Several reportedly successful installations were shut down at the time of the scheduled visit, had been abandoned, were being phased out of operation, or had never practiced co-incineration. Where the incinerator operators had abandoned co-incineration, the reasons were explored insofar as possible. Some of the incinerator plants where co-incineration was being or had been practiced had been visited by one or more of Roy F. Weston's professional staff before this study; others were visited as a part of this study to obtain additional background information. The incinerator plants visited before or during this study are as follows:

	Co-Incineration Technique (See Table 1)
Altrincham, England*	(5)
Ansonia, Connecticut*	(4)
Dieppe, France*	(4)
Dordrecht, Holland*	(8)
Franklin, Ohio	(3)
Holyoke, Massachusetts*	(4)
Kodak Park, Rochester, New York*	(6)
Nieder-Uzwil, Switzerland*	(2)
Orchard Park, New York (Torrax)	(7)
Reigate, England*	(2)
South Charleston, West Virginia (Purox)*	(7)
Waterbury, Connecticut	(6)
Whitemarsh Township, Pennsylvania	(1)

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*Plants visited during this study.

Reports on the visits which were a part of this study are in Appendix B, as are reports on selected contacts with incinerator operators, manufacturers, vendors, and others relative to co-incineration facilities and practices. The visit to the Dordrecht plant was a substitution for the planned visit on an incinerator at Bülach (Switzerland), which turned out to be permanently shut down. The manufacturer indicated that the type of equipment at Bülach was being phased out, and recommended the Dordrecht visit. Weston staff personnel have also visited many separate MMR (Mixed Municipal Refuse) and MSS (Municipal Sewage Sludge) incinerators in the course of previous investigative and design assignments.

During the course of this study, we became aware of a joint European investigation of co-incineration of refuse and sludge. This effort, under the chairmanship of Dr. R.S. Gale* of the Water Research Center in England, involved the testing of two co-incinerators: the multiple-hearth unit at Uzwil, Switzerland and the von Roll System in operation at Dieppe, France. The European reports have not yet been published.

OVERVIEW OF APPLICABLE TECHNIQUES

EPA designated seven principal co-incineration techniques for study:

1. Incineration of dewatered sludge filter cake and raw solid waste in a conventional solid waste incinerator.
2. Incineration of dewatered sludge filter cake in a multiple-hearth unit employing raw solid waste as an auxiliary fuel.
3. Combustion of dewatered sludge filter cake with raw solid waste in a fluidized-bed incinerator.
4. Utilization of waste heat from the combustion of raw solid waste to evaporate moisture from wet sludge (less than 10 percent solids) before incineration of sludge with refuse in the same combustion chamber.
5. Utilization of spray techniques to inject wet sludge directly into the combustion chamber of a refuse incinerator.
6. Utilization of flash evaporation techniques to feed wet sludge into a solid waste combustor.
7. The use of pyrolysis combustion techniques to co-incinerate refuse and sludge.

Weston conducted a literature search and made other contacts to identify plants where co-incineration of Mixed Municipal Refuse (MMR) and Municipal Sewage Sludge (MSS) has been practiced or planned. Table 1 lists the plants so

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*Dr. R.S. Gale, Head of Sludge Technology, Water Research Center, Stevenage Laboratory, Elden Way, Stevenage, Hertfordshire SG 1TH England, U.K.

TABLE 1. APPLICATIONS OF MHR/MSS CO-INCINERATION TECHNIQUES

Technique	Location of Installation	Remarks
1. Incineration of dewatered sludge filter cake and raw solid waste in a conventional solid waste incinerator.	Kewaskum, Wisconsin	Abandoned
	Whitemarsh, Pennsylvania	Abandoned
	Cheneviers, Switzerland	
	Frederick, Maryland	Abandoned
2. Incineration of dewatered sludge filter cake in a multiple-hearth unit employing raw solid waste as an auxiliary fuel.	Reigate, England*	Lurgi System
	Ebingen, Germany	Lurgi System
	Bülach, Switzerland	Lurgi System; abandoned
	Dübendorf, Switzerland	Nichols System
	Bowhouse, Alloa, Clackmannshire, Scotland	Lurgi System
	Uzwil, Switzerland*	Nichols System
3. Combustion of dewatered sludge filter cake with raw solid waste in a fluidized-bed incinerator.**	Franklin, Ohio*	Special
	Menlo Park, California	Demonstration Plant
	Lausanne, Switzerland	Tests Only
	Great Lakes Paper Co., Thunder Bay, Ontario, Canada	Tests Only
	Duluth, Minnesota	Proposed
4. Utilization of waste heat from the combustion of raw solid waste to evaporate moisture from wet sludge ($\leq$10 percent solids) prior to incineration of sludge with refuse in the same combustion chamber.	Ansonia, Connecticut*	Spray Dryer; being modified
	Holyoke, Massachusetts*	Rotary Dryer
	Dieppe, France*	von Roll System
	Stamford, Connecticut	Rotary Dryer
	Gluckstadt, Holstein, West Germany	Drag-Conveyor Dryer
	Krefeld, Germany	Flash-Drying System(probably)
	Harrisburg, Pennsylvania	Proposed
	Nurnberg, West Germany	von Roll System; proposed
	Hershey, Pennsylvania	Inactive
	Luleå, Sweden	Rotary Dryer

TABLE 1 (continued)

Technique	Location of Installation	Remarks
5. Utilization of spray techniques to inject wet sludge directly into the combustion chamber of a refuse incinerator.	Alrincham, United Kingdom	Abandoned
	Dickerson Station, Havant, United Kingdom	Proposed
6. Utilization of flash-evaporation techniques to feed wet sludge into a solid waste combustor.	Neenah-Menasha, Wisconsin	Shut down
	New Albany, Indiana	Shut down
	Waterbury, Connecticut	On standby
	Watervliet, New York	Shut down
	Bloomsburg, Pennsylvania	Abandoned
	Essen Karnap, West Germany	Proposed
	Newburgh, New York	Abandoned
	Eastman Kodak,* Rochester, New York	Special
	Louisville, Kentucky	Not co-incinerating
	Trenton, Michigan	Drying only
7. Pyrolysis	South Charleston, West Virginia*	Purox co-incineration; proposed
	Baltimore, Maryland	Monsanto System; 1/75 startup
	Orchard Park, New York	Torrax co-incineration; tested
	San Diego, California	Garrett System
	Kalnudborg, Denmark	Titan Thermogen System ; inactive refuse only
	Minneapolis/St. Paul, Minnesota	Proposed
8. Miscellaneous	Glouchester City, New Jersey	Abandoned
	International Paper Company Mobile, Alabama Georgetown, South Carolina Vicksburg, Mississippi	Sludge & Hogged Fuel
	Manistque Pulp and Paper Co. Manistique, Michigan	
	Farberjabriken Baya A.G., Laverkusen, Germany	Rotary Kiln

TABLE 1 (continued)

Technique	Location of Installation	Remarks
	Buick Motor Division, GMC, Flint, Michigan	Oily sludge only
	Plaine de Rhone, France	MacLaren System; proposed
	Pleasantville, New Jersey	Salt bath
	WIBAU Matthias Plant, South Germany	
	Riegal Paper Company Milford, New Jersey	
	Cologne, West Germany	Rotary Kiln
	Dordrecht, Netherlands*	Multiple Hearth
	Keller-Peukert System	Conceptual

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*Visited as part of the present study.

**None was identified as using raw solid waste. The listed installations used prepared solid waste as an auxiliary fuel.

identified under each of the seven principal co-incineration techniques, with appropriate remarks on status of operation and type of equipment. The listing on Table 1 also includes cities where serious attempts at co-incineration were made on an experimental basis, or where co-incineration has been practiced but abandoned.

The techniques did not always fit the specific requirements, yet were close enough to provide a satisfactory directory of existing technology in the seven specified categories of technique. This table also includes a final section, "Miscellaneous," for other plants where some form of co-incineration had been or was being practiced but where either the technique did not fit into any of the other categories, or the refuse and sludge involved were industrial in origin (and, therefore, with characteristics different from those of MMR and MSS). None of the approaches listed under Miscellaneous was considered sufficiently promising to justify designation as an additional principal technique.

Sludge Treatment

Another approach to categorizing co-incineration is the methods that have been used to treat and feed sludge with refuse. Methods I through IV entail separate injection of the sludge stream into the furnace; the only parameter that is different is the moisture content of the sludge at the time of injection.

Category	Type of Sludge	Type of Feed
I	Thickened	Direct Injection
II	Dewatered	Direct Injection
III	Direct-Contact Dried	Injection
IV	Indirect-Contact Dried	Injection
V	Thickened	Addition to Refuse before Feeding
VI	Dewatered	Addition to Refuse before Feeding
VII	Direct-Contact Dried	Addition to Refuse before Feeding
VIII	Indirect-Contact Dried	Addition to Refuse before Feeding

Items V through VIII entail addition of the sludge to the refuse before feeding to the furnace, and again each category represents a different degree of residual moisture content before the sludge stream is added to the refuse stream.

These methods are typical of the primary process steps that have been used in preparing sludge for incineration, but this broad categorization does not cover intermediate steps (e.g., sludge heat treatment and/or chemical treatment) that might precede the physical dewatering step. We have also not differentiated between the dewatering attainable by centrifugal, vacuum, or pressure filtration methods of physical dewatering. Likewise, the drying steps do not account for ultimate moisture content nor for the method used in drying the sludge other than differentiating between direct- and indirect-contact drying. This tabulation of methods of sludge treatment and feeding does not account for exactly how the sludge would be injected into the furnace or added to the refuse before feeding the furnace. Nevertheless, this list of methods provides the basis for assessing the impact and importance of the sludge processing steps.

Feed Method

Injection or addition of thickened sludge imposes the maximum thermal load on the furnace, because a large amount of water must be evaporated and heated to the furnace temperature. Physically dewatered sludge reduces the water quantity, thus easing the thermal requirements, which in turn permits a high sludge-to-refuse ratio. Reduction of sludge moisture beyond mechanical dewatering, by pre-drying the sludge using heat generated by the combustion of dried sludge and refuse, is one approach which eliminates many of the problems associated with the feeding and direct combustion of wet sludge (i.e., dewatered to 20 to 45 percent solids). Pre-drying, however, creates a potential odor pollution problem: the water vapor or wet gases emitted from the sludge dryer will contain organics distilled from the wet sludge in sufficient quantity to require odor destruction. The most logical means of such odor destruction is high-temperature incineration by re-injection of the gases into the furnace. Raising the temperature of such gases to at least 760°C (1,400°F) or higher, in the presence of air (oxygen), will result in the destruction of the odorous materials.

Reheating the dryer gases places an additional load on the incinerator. In direct-contact sludge dryers, the entire gas volume passing through the dryer, plus the evaporated moisture, is returned to the incinerator and must be reheated to 760°C (1,400°F). The flue gas is then exhausted to the atmosphere (through pollution control equipment which may require gas cooling), and significant quantities of heat are lost.

In indirectly heated systems, only the water vapor, plus small amounts of purge air and leakage, are returned to the furnace for odor destruction. While the gases are raised to 760°C (1,400°F) as required to destroy odors, a large portion of the flue gas enthalpy is recovered in the boiler, and the flue gas leaves the unit at temperatures between 150° and 260°C (300° - 500°F).

The allowable sludge-to-refuse ratio is higher when a drier sludge is fed to the furnace or dryer circuit. Any inerts or thermally unstable inorganics will represent a heat loss in the system, because the inerts must be heated, and because thermal decomposition of unstable inorganics is endothermic.

Table 2 has been prepared to summarize the status of furnace systems applicable to co-incineration of MMR and MSS. Note that the furnace systems

TABLE 2. STATUS SUMMARY OF CO-INCINERATION

Methods of Sludge Treatment and Feed								Municipal Refuse Furnace Systems (Continuous Feed)	Furnace Status	Principal Technique (See next subsection)	Energy Recovery		
I	II	III	IV	V	VI	VII	VIII				None	Steam	Fuel Gas or Oil
								A. Raw Refuse					
E	-	C	P	E	E	E	E	a. Grate firing	C	1,4,5,6	C	C	*
								b. Rotary Kiln					
E	E	P	P	E	E	E	E	1. Co-Current	P	4,5,6,7	P	C	C
E	E	P	P	E	E	E	E	2. Counter-Current	P	4,5	P	P	E
E	E	P	P	E	E	E	E	3. Two-Stage	P	4	P	P	E
								c. Shaft Furnace					
E	E	E	E	E	E	E	E	1. Air-Blown	E	7	C	P	P
E	E	E	E	E	E	E	E	2. Oxygen-Blown	E	7	*	P	C
								d. Combination Furnace					
E	*	P	P	E	E	E	E	1. Grate Plus Rotary Kiln	C	1,4,5,6	C	C	*
								B. Shredded Refuse					
								a. Grate Firing					
E	E	P	P	E	E	E	E	1. Spreader Stoker	C	1,4,5,6	P	C	*
								b. Suspension Firing					
E	E	P	P	E	P	E	E	1. Utility Furnace (Fossil-Fuel Fired)	P	4,5,6	*	C	*
*	E	C	*	*	*	E	E	2. Industrial Furnace	C	4,5,6	*	C	*
E	E	E	E	E	E	E	E	3. Cyclonic	E	--	E	E	*
								c. Multiple Hearth					
*	*	*	*	P	C	*	*	1. Mixed Feed	C	2,7	C	P	P
P	C	*	*	*	*	*	*	2. Dual Feed	C	2	C	P	*
								d. Fluid Bed					
P	P	*	*	P	P	*	*	1. Top Feed	P	3	C	P	C
P	P	*	*	P	P	*	*	2. Dual Feed	P	3	P	P	*

C -- Commercial (one or more installations)
P -- Possible (practically similar to commercial, or proposed commercially)
E -- Experimental (work needs to be done)
* -- Unsound, undesirable, unnecessary (redundant), etc.
Source: Estimates prepared by Roy F. Weston, Inc.

are divided into two categories: those which are capable of handling raw refuse as received (exclusive of bulky items), and those which require shredded refuse for firing. The techniques which could be used with each furnace system are noted, along with the potential for energy recovery, in terms of whether the system can be considered commercial, possible, experimental, unsound, undesirable, unnecessary, redundant, etc. The advantages and disadvantages of each of the seven principal co-incineration techniques are discussed in the next sub-section.

DISCUSSION OF PRINCIPAL CO-INCINERATION TECHNIQUES

Synopsis

Following is a brief description and experience summary for the seven co-incineration techniques studied. A more detailed discussion, including reports on individual plant experiences, is included in the detailed discussions appearing later in this section.

Technique Number 1: Incineration of Dewatered Sludge Filter Cake and Raw Solid Waste in a Conventional Solid Waste Incinerator--

This technique involves the direct injection of sludge cake into the active combustion zone of the incinerator. A number of plants have attempted co-incineration using this technique, with poor results. Difficulties included problems with dispersing a high-solids sludge cake throughout the combustion zone and poor ignition and burn-out of sludge cake. This technique requires a minimum in capital investment and was the first co-incineration technique to receive serious consideration; however, all plants that employed this co-incineration technique have been abandoned.

Technique Number 2: Incineration of Dewatered Sludge Filter Cake in Multiple-Hearth Incinerator Using Solid Refuse as an Auxiliary Fuel--

The technique employs shredded refuse to improve the "average" heating value of dewatered sludge cake for incineration in a multiple-hearth unit. Several successful operations can be found in Europe, although no U.S. installations are currently in operation. Advantages of this technique include extended residence time, zoned temperature control in the furnace, excellent sludge/refuse mixing, and standard equipment design. The major disadvantage of this system is the extensive refuse shredding and cleansing necessary with multiple-hearth furnaces.

Technique Number 3: Combustion of Dewatered Sludge Filter Cake and Raw Solid Waste in a Fluidized Bed Incinerator--

No plants routinely using this co-incineration technique were identified. A number of experiments have been run using refuse and refuse-like fuels to provide the additional heat necessary to incinerate sludge. The major advantages of fluidized bed combustion include the availability of a large heat sink in the sand bed, thereby maintaining satisfactory operating conditions with wide variations in sludge feed rate and moisture. In addition, the fluidizing action provides excellent mixing of the refuse and sludge. As with multiple-hearth incinerators, extensive refuse preparation in the form of shredding and air classification will most likely be required for this technique.

Technique Number 4: Utilization of Waste Heat from the Combustion of Raw Waste to Evaporate Moisture from Wet Sludge Prior to Incineration of Sludge with Refuse in the Same Combustion Chamber--

In this technique, sludge is pre-dried before it is combined with the refuse for incineration. The burning sludge and refuse provide much, if not all, of the heat necessary for pre-drying the sludge. In all cases, the sludge is pre-dried in a processing unit separate from the actual incinerator. Heat may be transferred from the incinerator to the dryer by direct use of incinerator flue gas or by the production of steam which is later used in the sludge dryer. Co-incineration facilities have been successfully operated using both these techniques. By pre-drying the sludge, the operation of the incinerator portion of the process is greatly facilitated. Separation of the drying and incinerrating facilities also permits independent operation of either unit. The major disadvantage is the increased operating and capital cost of two processing units. This technique appears to be the most widely used and successful co-incineration process.

Technique Number 5: Utilization of Spray Techniques to Inject Wet Sludge Directly into the Combustion Chamber of a Refuse Incinerator--

This technique is actually a modification of Technique Number 1. Proved means of spraying or dispersing the sludge in or above the active combustion zone are included to improve the ignition and burn-out of sludge solids. There are no facilities currently using this technique, although one plant was in operation for an extended period. Spraying a low-solids sludge obtains better atomization, and the sludge solids are more readily dried and ignited. However, the need to maintain low solids in the spray system led to the eventual failure of this technique.

Technique Number 6: Utilization of Flash Evaporation Techniques to Feed Wet Sludge into a Waste Combustor--

Technique Number 6 is a special adaptation of Technique Number 4. Incinerator flue gas is used as the heat source in pre-drying sludge. This system has been separated because it has a well-known developer, the Raymond Division of Combustion Engineering. In addition to drying sludge, the flash evaporator (normally a cage mill) comminutes the sludge particles for direct firing into the incinerator or into a boiler. The dried sludge can also be separated and sold as fertilizer or soil conditioner. A number of units have been installed and operated, using both refuse and fossil fuels as heat sources. Of late, the system appears to have lost much of its early popularity. Disadvantages of this technique appear to be extensive equipment corrosion and erosion, critical operating parameters, potential for dust explosion, and for the generation of extremely fine particulate material which is carried through the incinerator to collection equipment.

Technique Number 7: Co-incineration by Pyrolysis--

Pyrolysis is a recent development in municipal refuse disposal designed to recover some of the energy resource in convenient form. Other than demonstration plants built by vendors, there are no operating units in the U.S. Early indications are that co-incineration in such units may be practical with the loss of some of the potentially recoverable energy in the refuse. Feasibility studies and demonstrations are currently under way.

Technique 1: Incineration of Dewatered Sludge Filter Cake and Raw Solid Waste in a Conventional Solid Waste Incinerator

Four plants were identified where this technique had been or was being used. All the domestic sites have abandoned co-incineration, and there is good reason to believe that this technique has been attempted but unreported at a great many more plants, because it is one of the simplest methods possible for the disposal of MSS along with MMR. Lancoud[1] has reported on a Swiss incinerator where dewatered sludge was added to the raw MMR and fed to a 180 metric ton per day (200-tpd) continuous-feed, grate-fired, steam-generating incinerator. The heat-treated MSS was filter-pressed to 40 percent moisture, and the cakes were broken up before the sludge was added to the refuse. Because there seemed to be an excessive amount of combustibles remaining in the ash, a series of tests was run in June 1969. The test data indicated that none of the sludge was incinerated. Lancoud concluded that the MSS was not satisfactorily destroyed by incineration, for the following reasons:

1. The pieces of sludge cake are larger than refuse and move faster through the furnace; thus, burning time is reduced.
2. A crust formed on the sludge cake hinders complete combustion.
3. Poor mixing permits sludge cakes to separate from the refuse, with poor air contact and resulting poor combustion.

Lancoud suggested the following remedial action:

1. Reduce the size of the sludge cake to 2 cm (0.8") or less.
2. Use mechanical action in the incinerator to break up the crusted cakes (some mechanical action during test sequence).
3. Improve the mixing of the sludge cake and MMR before they are fed to to the furnace.

Clinton[2]* has reported on the Kewaskum Incinerator, a batch-feed furnace with a capacity of 23 metric tons/day (25 tpd). The primary and secondary sludge was vacuum-filter-dewatered and added to the raw refuse before charging the furnace. Reportedly,** the plant stopped burning sludge in the furnace after a short time, because the heat supplied by the refuse to burn the dewatered sludge was insufficient.

Reilly[3] has reported on the original Whitemarsh incinerator, which was dedesigned to mix vacuum-filter-dewatered MSS with the refuse prior to feeding the furnace. The author reports a five-day performance test during which 29 metric tons (32 tons) of sludge were burned with 346 metric tons (381 tons) of refuse, a sludge-to-refuse ratio of 8.4:100. The test was reportedly sucessful, but the original incinerator failed, and further attempts to burn MSS were abandoned because of burning problems.

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*The papers referenced in this section are also abstracted in Appendix A.

**Verbal communication with Mr. Peter Alberts.

Defeche[4] has reported on the combined disposal of refuse and sludges, specifically referring to the Swiss plant reported on by Lancoud. In addition, Defeche reports on a series of short-term co-incineration tests that were conducted at Locarno, Sutton Coldfield, Rotterdam, and Issy-Les-Moulineaux. He reported that the carbon content of the residue at Rotterdam increased with co-incineration, and that at Issy-Les-Molineaux there were several tests during which the sludge stuck to the feed hopper and steam production dropped. In general, Defeche stated that the co-incineration tests were successful, but the kind of problems that developed in Switzerland could not have been observed, because all the tests were short-term.

Knaak and Kuhl[5] have reported on co-incineration experiments at the Gentofte incinerator in Copenhagen and at the incinerator at Bad Godesberg. Both incinerators are grate-kiln-fired, continuous-feed, steam-generating incinerators. The author reports on four sludges and several dewatering processes and on four methods of adding the sludge to the furnaces: 1) sludge continuously added to the refuse fed by a spreader; 2) sludge mixed with the refuse in a trommel before feeding to the furnace; 3) a full bucket-load of sludge placed in the feed chute; and 4) sludge manually added by shovel into the feed chute. Knaak and Kuhl reported that the only problem encountered was the formation of crusts on the sludge cake, which hindered the drying and burning of these pieces.

Frederick, Maryland[6] has reportedly mixed dewatered MSS with MMR before feeding it to the furnace, but contact with plant operators indicated that the reasons for abandonment were lost in the fog of time. While undoubtedly one of the simpler systems, the limited experience available would seem to indicate that intensive mixing of the MSS with the MMR is a prerequisite to successful implementation of this technique.

Lancoud's conclusion, that improved mixing of the sludge cake and refuse is a mandatory requirement, seems valid. It is difficult to conceive of a simple system that would adequately mix dewatered sludge cake with a material that is as heterogeneous as MMR. We do not consider this technique feasible without extensive development work and cannot forecast a successful conclusion of the current developmental work.

Technique 2: Incineration of Dewatered Sludge Filter Cake in a Multiple-Hearth Unit Employing Raw Solid Waste as an Auxiliary Fuel

Six plants were identified as using this technique, with a slight modification; i.e. a prepared (shredded) refuse was used in place of raw refuse. No U.S. installations were identified, although it is very likely that the technique has been tried in existing multiple-hearth furnaces intended for drying or burning MSS. However, tests have been reported[7] at Envirotech Corporation's Brisbane, California test facility, and the Metropolitan Waste Control Commission - Twin Cities Aera has received an EPA research grant to study co-incineration of sewage sludge with refuse and/or coal. The European and English installations can be divided into two classes: 1) those that feed refuse and sludge to the top hearth of the furnace; and 2) those that feed sludge to the top hearth and feed refuse to some mid-point hearth.

The Dubendorf installation has been described in an anonymous[8] 1969 article. Here, thickened sludge (90-95 percent water) is mixed with ground refuse and fed to the top hearth of the furnace. This furnace also accommodates waste oils, which are separately fed to a mid-hearth of the furnace.

Kiefer[9] and Burgess[10] have described the Ebingen plant, where the waste is shredded in a hammermill and magnetically cleaned before being added to the second and third levels of the multiple-hearth furnace. The sludge is added to the uppermost level and is dried, before reaching the combustion zone, by the waste gases from the combustion of MMR. The sludge fed is dewatered to 60-65 percent water, and 36 tons of sludge are fed for every 100 tons of refuse. stated that the additional energy necessary for incineration at 700°-800°C (1,300°-1,500°F) is introduced in the third and fourth levels of the furnace, where the actual incineration takes place.

Contacts with various individuals indicate that there are no odor problems with multiple-hearth systems where sludge and refuse are introduced in the top hearth, because the discharge temperatures are relatively stable at approximately 600°C (1,100°F). The Uzwil plant is said to be recognized by the Swiss Government as a model plant; however, magnetic separation of ferrous metals from the shredded refuse is essential, because any ferrous metal (particularly wire) not so removed from the feed would foul the plows on the rabble arm or plug the hearth drop holes.

The Bulach plant, where sludge was dried on the upper hearths and refuse was fed to the mid-hearths, had been plagued with odor problems that could not be technically resolved, because the upper hearths performed a drying function and the flue gas temperature leaving the unit was about 100° to 200°C (200°-400°F). Doubling the height of the discharge stack could overcome the problem by providing significantly greater odor dissipation, but would not attack the root cause of the problem (low flue-gas temperature). Furthermore, the wide variability in heat content of the feed material made it difficult to maintain off-gas temperatures; consequently, even with higher off-gas temperatures, there were periodic odor episodes. These circumstances could have been significant in the reported abandonment of the Bulach plant.

At Reigate, a number of solvable problems had been encountered with a Lurgi multiple-hearth furnace, including the need to re-insulate the central shaft of the furnace because of problems with local overheating, which could have been caused by receiving refuse with a high Btu content or by problems in maintaining the insulating material on the exterior of the drive shaft.

The applicability of multiple-hearth furnaces to co-incineration was discussed with a representative of a domestic vendor. The general conclusions were that many of the problems will be associated with the refuse pre-processing step and that adequate cleansing of the refuse to remove those materials likely to cause problems within the multiple-hearth furnace is both mandatory and solvable.

In conclusion, the dual-feed multiple-hearth furnace (such as Bulach) has inherent odor-emission problems. A properly designed, top-feed, multiple-hearth installation (Uzwil) would seem technically and practically possible, except that there are built-in size constraints in this type of system.

Technique 3: Combustion of Dewatered Sludge Filter Cake with Raw Solid Waste in a Fluidized-Bed Incinerator

All the fluidized-bed incinerators that were identified in the survey used a prepared refuse rather than raw refuse.

The Franklin, Ohio system (visited some time ago by Weston personnel) constitutes a very special means of using the fluid-bed incinerator on MMR, in that extensive refuse preparation and resource-recovery steps precede the feeding of the residual MMR to the fluid-bed unit. A wet pulper is employed at Franklin, and ferrous metal, heavy solids, etc. are removed from the waste stream. Liquid sludge is then mixed with the prepared refuse before the residual material is dewatered in a cone press and pneumatically conveyed and injected into the furnace above the sand bed level. No problems that could be attributed to the accumulation of coarse material in the bed (which would tend to de-fluidize the bed) have been encountered on this installation; however, it has been necessary to remove excess bed material periodically, rather than add to the bed material as is common when fluid-bed incinerators are used to burn sludge only. The Franklin unit, with a diameter of 7.3 m (24 ft), is one of the largest in existence and approaches the maximum size available for this type of equipment. There are severe design constraints associated with the constriction plate under the sand bed which feeds the fluidizing/combustion air to the fluid bed unit. Herber[11] has reported on the Franklin installation in a paper, "Waste Processing Complex Emphasizes Recycling."

Albrecht[12] has reported on the fluid-bed sludge incinerator in Lausanne (Switzerland), where the sludge is fed by gravity through a pipe that penetrates the reactor head into the furnace freeboard. Experiments have been conducted at this site by adding a variety of solid waste materials to the sludge feed. The author reported excellent combustion of these materials, which were largely fine to begin with or were totally combustible.

Limerick[13] has reported on the fluid-bed unit at Thunder Bay, Ontario, which, although not typical of municipal refuse or municipal sludge, is handling hogged bark and wood debris along with pulp mill sludge, and has been tested on MMR. Unsorted solid waste from the City of Thunder Bay has been burned along with sludge at Great Lakes Paper Company, as a demonstration of fluid-bed furnace operation. Duluth, Minnesota is the proposed site for two fluid-bed units to burn prepared refuse and sludge. The refuse will be shredded, magnetically separated, and air cleaned before being fed to the furnace. The system will include a waste-heat boiler, and the steam will be used to power the plant's prime movers.

Fluidized-bed furnaces are considered competitive with multiple-hearth furnaces for the combustion of MSS. In sewage sludge combustion, a certain amount of the sand is lost from the bed and must be made up. At Franklin, Ohio the bed attrition problem probably exists, but, at the same time, excess bed material must be periodically drained from the unit. It is known that large materials will accumulate at the bottom of the fluid bed, causing ultimate defluidization of the bed; therefore, it is important that the refuse be shredded to a uniform size, generally in the 2.5 cm to 7.6 cm (1" - 3") range.

As long as the materials introduced to the bed unit have a maximum size not greater than the consist of the bed material, there should be very little problem in burning MMR and MSS in the same unit. In all probability, the degree of shredding would have to be much greater with the fluidized-bed unit than with the multiple-hearth unit, and cleansing of the material would appear important, to prevent excessive down time (for removal of material from the furnace). Since all the fine ash introduced to a fluidized-bed unit goes out the overhead, the particulate loading to the control equipment will undoubtedly be high, but certainly controllable by cyclones and venturi scrubbers normally used with fluidized-bed incinerators.

Other problems of using a fluidized-bed unit involve size limitations which are slightly more restrictive than in the multiple-hearth unit. In addition to size, the density of the shredded refuse must be uniform. Extremely dense material will drop through the fluidized bed and can cause blockage and disturb the flow through the air distribution plant under the sand bed.

The refuse preparation and cleansing train is essentially a solvable problem, with built-in capital and operating cost constraints that are unique to this type of system.

The final problem involves the best method of feeding the MMR and MSS to the furnace. Two of the four principal fluid-bed manufactuers introduce sewage sludge into the fluidized bed; the other two introduce the sludge through the freeboard of the furnace. There are several other manufacturers who would introduce material through the freeboard in a fashion similar to that used at the Lausanne installation. If shredded MMR must be introduced through the freeboard it is possible that material will be blown out of the furnace before combustion is complete; this does not appear to be an insurmountable problem, but none of the manufacturers offers a system of MMR introduction that would clearly overcome the problem of unburned material leaving the freeboard of the furnace before combustion is completed.

In summary, the fluidized bed method of co-incineration is reasonably well established theoretically, with some practical experience to indicate that a full-scale installation would be wholly practical.

Technique 4: Utilization of Waste Heat from the Combustion of Raw Solid Waste to Evaporate Moisture from Wet Sludge (Less than 10 Percent Solids) Prior to Incineration of Sludge with Refuse in the Same Combustion Chamber

Ten existing or proposed installations were identified, although not all of them can be properly classified as handling wet sludge containing less than 10 percent solids. Each of the systems identified can be termed a refuse incinerator; the major variables are the method of drying the sludge and the method of injecting or adding the dried sludge to the furnace or to the refuse.

The sludge drying methods can be broadly categorized as direct utilization of the hot flue gases for direct-contact drying of the sludge, and utilization of steam or an intermediate hot fluid to dry the sludge indirectly.

The Ansonia, Connecticut installation (see Appendix B) utilizes a spray dryer, and is apparently the only application of the spray drying technique to sludge drying in incineration practice. The system has undergone several changes, with one change under way at the present time. The present location of hot flue gas takeoff from the incinerator ductwork has provided the spray dryer with inlet gas temperatures below design conditions, thus reducing the dryer capacity. By relocating the takeoff to the primary combustion chamber, gas temperatures of 980°C (1,800°F) are expected to restore dryer capacity.

The Holyoke, Massachusetts[14,15] and the Stamford, Connecticut[16] installations utilize rotary dryers. The Holyoke installation has been in use for many years, while the Stamford installation was just started up recently (1975).

Tanner[17] has reported on the von Roll indirect sludge-drying system to be used at Dieppe, where steam will provide the heat for a scraped-surface sludge evaporator. Another system of this type has been proposed for Nurnberg in West Germany.

Joachim[18] has reported on two sludge-drying schemes. One of the schemes uses a direct-contact drag-conveyor dryer, and the other uses an indirect-contact drag conveyor; both use hot gas as the heating medium. One installation is planned for Gluckstadt, West Germany.

Pepperman[19] has reported on the planned modification of the Harrisburg, Pennsylvania incinerator to burn MSS. In a personal communication, Pepperman indicates that the thickened sludge will be pumped to the incinerator site and that a sludge-processing building will be built adjacent to the existing incinerator. In the processing building, the sludge will be heat-treated, vacuum-filtered, and steam-dried to a moisture content between 10 and 15 percent using steam from the refuse incinerator for the heat treatment and drying. After it has been dried, the sludge will be pneumatically conveyed in a 5 cm (4") steel pipe to an elevator installed in the incinerator building. From the elevator, the sludge will be discharged to one of the two incinerator-charging hoppers utilizing screw conveyors for that purpose. Since the charging hoppers are 5.5 m (18 feet) long, the sludge will be discharged at the quarter points, to obtain suitable mixing with the refuse. The spent air from the pneumatic conveyors will be discharged to the combustion-air intake chamber on the roof of the incinerator and then used as over-fire or under-fire air. In addition, the vapor-laden air from the steam dryers or evaporators will be conveyed in ducts from the sludge processing building to the incinerator, where it will be used as over-fire air, thereby eliminating potential odor problems.

The Holyoke, Massachusetts installation, which apparently was the first application of a rotary dryer to co-incineration of MSS and MMR, was visited in the course of this study. The plant consists of two batch-fed furnaces with a combined capacity of 204 metric tons per day (225 tpd). The incinerator operates 8 hours a day, burning 50 metric tons (55 tons) of mixed municipal refuse (including a significant quantity of paper waste from nearby mills).

The wastewater treatment plant employs primary treatment only, producing about 49 metric tons per day (54 tpd) of thickened (5 percent solids) sludge. The sludge is dewatered through vacuum filters, producing a 28 percent solids filter cake.

The cake is premixed with previously dry sludge, increasing solids to about 50 percent, to reduce deposits on the dryer wall. The sludge is then dried in a 2.1 m (7 ft) diameter by 12.2 m (40 ft) long direct-fired steel-shell rotary dryer. Sludge leaving the dryer contains about 15 percent moisture. The sludge solids are conveyed to either incinerator and injected into the furnace by a high-velocity air jet.

Hot gas to dry the sludge is drawn from the incinerator flue and tempered to 650°C (1,200°F). The gases pass in co-current flow through the dryer and are returned to the incinerator stack breaching. Auxiliary fuel is fired, as required, at the dryer inlet.

The plant has been co-incinerating sludge and refuse with little difficulty since 1965. Initially, no auxiliary fuel was required, because large quantities of high-heating-value waste paper were present in the refuse load. When environmental regulations required a reduction in the quantity of coated paper incinerated, some auxiliary fuel was required. In addition, the intermittent operation of the plant (8 hours/day, 5 days/week) also increased the quantity of auxiliary fuel required. Further details are reported in Appendix B.

An anonymous[20] publication concerning the Krefeld installation lacks the detail necessary for positive identification of the method, but describes it as using furnace flue gases to dry the sludge before blowing it into the main combustion zone. This particular installation may be Technique 4 or could be Technique 6.

Gater[16] has reported on the Stamford, Connecticut installation, where the sludge will be dried in a rotary dryer and then injected into the combustion chamber of a conventional refuse incinerator.

Bergling[21] has reported on an installation in Lulea, Sweden, where the hot gases from each of two 330 metric ton/day (360 tpd) refuse incinerators pass through a rotary dryer-incinerator. This installation does not, strictly speaking, fit within the technique being discussed, because the sludge is either dried or incinerated in the rotary unit rather than introduced to the combustion chamber of the MMR incinerator.

Defeche,[4] in reviewing the combined disposal of refuse and sludges, also referred to the Dieppe furnace, stating that flue gas or steam can be used in the thin-film evaporator.

Samuels[22] has described a system where sludge is dried in a screw conveyor arranged for heat transfer by means of a jacketed shell and hollow screws. The system uses 320°C (600°F) oil, and the heat necessary to raise the oil to that temperature is obtained by burning the dried sludge in an incinerator.

Schlotmann[23] has described a number of processes for co-incineration of refuse and sludge. One of them utilizes the excess heat from refuse incineration to provide the heat for a thin-layer evaporator; the vapors from the heat exchanger go into the incinerator and are heated to 800°C (1,470°F), while the sludge is further dried in a mill dryer before it is blown into the furnace.

Taylor[24] has discussed three methods of burning sludge with refuse, two of which involve this technique, using either direct gas-phase contact with the products of combustion, or indirect drying using an intermediate heat transfer fluid such as steam. The author concluded by recommending, on the basis of practicality, the indirect drying system using a thin-film evaporator fitted with a rotor and scraping blades to keep the heat-transfer surfaces clean. The system the author recommended is the one installed at Dieppe. He further stated that the vapors and incondensible gases from the evaporator are ducted into the furnace and heated to 750°C (1,380°F) to prevent odor emissions from the raw refuse incineration plant. Tanner and Vrenegoor in another paper[25] also have described the thin-film evaporator, stating that the dried sludge is metered into the feed hopper of an MMR incinerator and burned on a grate system.

Thompson[26] has described several systems, including one in which multiple-effect evaporation is used to dry the sludge prior to firing. The author stated that a multiple-evaporation experimental plant has been run for 1,800 hours in Hamburg, Germany, but there was concern about caking of the sludge on the coils as a major constraint of this system.

A multiple-effect evaporator has been used to dry MSS at Hershey, Pennsylvania (see Appendix B). The system uses an oil carrier to maintain sludge fluidity as water is removed through successive evaporation steps. Sludge solids are then separated from the oil in a centrifuge. Most of the oil is recycled to the evaporators. The oily sludge solid is then burned in a boiler to raise steam to drive the evaporators. The use of multiple-effect evaporators improves the energy efficiency of the entire process. The plant experienced problems with corrosion and erosion in the evaporator system. The corrosion from one effect to another was reduced by the injection of a small quantity of ammonia to neutralize organic acids which distilled with the evaporating water. The erosion problem, as the sludge was dehydrated, was a more serious problem which was never completely solved. The evaporator is presently shut down and will probably be abandoned in the near future.

Direct-contact drying of MSS has received considerable attention, and there are a number of installations both here and abroad. Potential odor problems seem to mandate return of the spent dryer gases to the hot zone of the MMR furnace. One reported problem (maintenance of dryer inlet temperatures) would appear solvable by employing a variation of the Lulea technique, in which waste oils can be burned in the dryer circuit.

Indirect-contact drying has received some attention, but the only installation appears to be in Dieppe, France. Domestic installations have been proposed, but none has been implemented. Indirect drying has a very real advantage over direct-contact drying, because the flue gases need not be reheated. The major problems are heat-transfer surface fouling and lack of demonstrated methodology.

On balance, both direct- and indirect-contact drying appear feasible, if it is assumed that sludge drying is necessary before injecting MSS into the furnace or before adding the dried sludge to the MMR when feeding the refuse furnace. The history of Techniques 1 and 5 lend credence to this assumption. The degree of dryness needed is one variable, as is the degree of physical agitation required during the drying operation. The recycle of dried sludge is practical in direct-contact drying and has been used in indirect drying to abate surface fouling.

Both direct and indirect sludge drying techniques before MSS combustion are proposed for further study. Techniques 4 and 6 should be examined together, since either can employ the hot flue gases to dry MSS.

Technique 5: Utilization of Spray Techniques to Inject Wet Sludge Directly Into the Combustion Chamber of a Refuse Incinerator

Only one operating plant and two proposed plants involving this method were identified. There is one plant in Europe which is conducting a short-term experiment to evaluate the method.

Davies[27] has described the Altrincham incinerator, a 196 metric ton/day (216 tpd) plant consisting of two continuous-feed, stoker-fired, refractory-wall furnaces complete with evaporative gas conditioning systems and electrostatic precipitators. The plan called for raw sludge at 5 percent solids to be sprayed into the furnace through the end walls of each furnace. The wet sludge feed rate was to be 76,000 liter/day (20,000 gpd), based on a five-day week. Co-incineration at this site has been abandoned, for two salient reasons: 1) the refuse was wetter than anticipated; 2) the injection pipe to obtain the desired wet sludge rate had to be small and was thus subject to frequent plugging. The engineers have calculated that the feed pipe would have to be 7.6 cm (3 in.) in diameter in order to prevent plugging problems and, thus, that the wet sludge feed rate would far exceed the capacity of the furnace to handle thickened sludge.

Munro[28] has reviewed the disposal of sewage sludges, and concluded with a description of a full-scale installation for the incineration of sewage sludge with domestic refuse on a continuous burning grate. The author mentioned Altrincham, Reigate, and Havant, stating that there are two basic ways that sludge can be incinerated in a continuous-burning domestic refuse incinerator. One method is spraying the sludge into the furnace chamber above the refuse bed, and the other is mixing sludge cake with the refuse fed to the furnace. At the Havant incinerator site, it is proposed to spray thickened sludge into the furnace using a dual fluid spray nozzle. Limited trials using the spray nozzle were made, but with 3.5 percent solids sludge rather than the 7-8 percent solids sludge expected to be used in the full-scale installation. Munro emphasized the importance of atomization, if drying and solids combustion are to be achieved, and pointed out that in order to destroy odor the temperature should be about 830°C (1,530°F). This temperature imposes a limitation on the amount of wet sludge that can be sprayed into the furnace. The refuse furnace at Havant is operating, and an addition of the sludge system is scheduled for late 1975.

Herrman, et at.[29] have discussed the proposed Dickerson Station and its plan to inject sludge into a coal-fired utility boiler along with prepared refuse. The contract for the furnace has been let and the basic furnace confuguration has been established, but the plans for the proposed adjacent wastewater treatment plant have not yet been finished. If the plnat is built on this site the plan is to inject dewatered sludge at 13 percent solids into the top of the furnace through two sewage sludge guns. The author stated that the total heat input from dry solids in the sewage sludge will amount to approximately 0.5 percent of the unit's maximum continuous rated heat input; this would be approximately equivalent to the heat required to evaporate the sludge moisture. In order to avoid possible plugging problems, the sewage must not contain more than 25 percent of its solids at a size of 100 percent minus 8 mesh and 90 percent minus 30 mesh. The sludge will be injected at a point where there will be four levels of coal nozzles below the point of sludge injection and three levels of coal nozzles above.

The failure of the Altrincham installation, where no further work is planned, and the proposed nature of the Havant incinerator and of the Dickerson Station make it difficult to directly assess the capabilities of this method, except by analogy to known problems. The major problem would be to sufficiently atomize the sludge such that it will both dry and burn within the confines of the furnace. Extremely high pressures and small orifice sizes are necessary to obtain fine droplets simply by mechanical atomization of water. Dual fluid spray nozzles utilizing compressed air or steam have the potential of producing a finer-size consist of sprayed material. The fibrous nature of MSS suggests that considerable experimentation would be necessary to determine the optimum combination of dual fluid spray nozzle, nozzle location, and throughput rate.

In spray-drying practice, a rotary disc atomizer has been used. There are no recorded uses of a disk-type atomizer for sludge disperson inside a refuse incinerator. Such disk atomizers have been used in experimental spray dryers (Ansonia, Technique 4), with 4 percent solids. Another approach would be to use a rotary cup burner assembly, as has been used for high-firing heavy fuel oil. Again, all of these approaches would require considerable experimentation to determine if satisfactory atomization could be achieved, and then, within the confines of a furnace, whether that degree of dispersion would yield drying and burn-out in the furnace.

Another analogous situation is the method of feed used on certain types of fluid-bed sludge incinerators where the sludge is introduced from the roof of the vessel through the freeboard of the furnace to the sand bed. The spray nozzle in this case is a rather crude assembly, and photographs taken by the manufacturer showing the dispersion pattern under test conditions in ambient air would seem to indicate that this type of injection method would not be suitable for a conventional refuse incinerator. Fluid-bed units of this type inspected by Weston staff members have not had observation ports, thus making it impossible to observe the descent of the sludge solids through the freeboard to the sand bed. As a result, we can speculate no further than is visually evident from the photographs supplied by one of the manufacturers.

Altrincham has abandoned this approach for operational reasons, but the thermal load problems should not be overlooked. At Altrincham, they proposed burning only a portion of the sludge generated in the refuse service area. Thickened sludge is difficult to feed, and dewatered sludge feed has not been proposed at either Altrincham or Havant. Clearly, dewatered sludge would be more difficult to atomize; therefore, for the present, it appears impractical to forecast using this method to feed sludge with a higher solids contents to reduce the thermal load on the system. While this approach is basically simple, the available hardware to achieve the desired results when feeding thickened sludge cannot be extrapolated from existing data without a considerable amount of experimental work. We therefore consider this technique, within the constraints of available hardware, as not a viable approach to co-incineration. The major problem with direct sludge injection into the furnace can be summarized as the increasing difficulty in atomizing or properly spreading sludges of increasing moisture content. We know from the experience reported at Altrincham that the injection of high-moisture-content, easily atomized sludge is not a viable technique. Further development in this technique should be directed toward techniques and equipment for the dispersion of high-solids (greater then 20 percent) sludge cake into a refuse incinerator. High-speed disk atomizers, high-velocity jet atomizers, sonic atomizers, pre-blending sludge cake with ash to increase solids, sludge cake comminution before injection, and means of pre-mixing sludge and refuse are techniques for sludge introduction directly into the combustion zone of the furnace which hold promise for this technique.

Technique 6: Utilization of Flash Evaporation Techniques to Feed Wet Sludge into a Solid Waste Combustor

A total of ten plants where co-incineration involving this technique could have or had been practiced were identified (see Appendix B). Most of these plants had been abandoned for one reason or another; of the remainder, the Neenah-Menasha incinerator was shut down around the first of 1975, the shutdown being dictated by the need to add air pollution control equipment to an already old incinerator. The Neenah-Menasha job constitutes a special case, since both the refuse fired and the sludge had a high heating value when compared to normal MMR and MSS, because large quantities of paper were in the refuse load and because there were significant amounts of fines (cellulose) in the pulp mill wastewater treated at the municipal plant.

The Waterbury, Connecticut plant[30,31] is on standby and could be operated, but the sludge is normally disposed of in a multiple-hearth sludge incinerator. The flash drying system was not expanded when secondary water treatment greatly increased the sludge volume. A multiple-hearth furnace is now in use.

At Essen-Karnap,[32,33,34] sludge has been burned with coal, and the use of refuse has been proposed. The system incorporates a dryer mill that blows the dried sludge solids into the furnace.

The Eastman-Kodak installation (see Appendix B) is a recent one and is special, because the refuse and sludge are industrial rather than municipal in origin. The installation also is a steam-generating furnace handling shredded refuse, with the dried sludge injected and burned in suspension.

The Newburgh, New York installation (see Appendix B) is a fairly recent installation of a Raymond flash-drying system, and personal contact with the plant indicates that the system was purchased in 1970 and abandoned after a year of attempts to get the system operational. Newburgh reports that to start the operation the MMR incinerator temperature was raised to 930°C (1,700°F) by burning cardboard, and that the hot gases were then directed to the flash dryer; as long as they were trying to dry sludge the incinerator temperature would drop drastically--at times reaching temperatures as low as 260° (500°F). As the temperature got lower, the drying process slowed, and the partially dried sludge clogged the materials-handling equipment, filling the building with smoke. The operator reported that the incinerator is a very old one with many leaks and poor draft control. The superintendent believes that this was the cause of poor operation and that the system would work with a modern incinerator. They attempted to start up again in 1974, with much the same results as in the original startup.

While Combustion Engineering has merchandised the Raymond dryer system in this country for many years, it is surprising to learn that there is only one operating unit where co-incineration is practiced--at Eastman-Kodak--a special situation, because the refuse and sludge are industrial in origin.

The Allegheny County[35] sludge incinerator is reported to be one of the best-operated sludge incinerators of the Raymond type in existence. The support fuel at this facility is not refuse, but coal or natural gas; nevertheless, some of the problems encountered would be typical of the Raymond system installed for co-incineration, with the exception that the support fuel used at Allegheny County has a controllable heat release whereas refuse does not. At the Allegheny County facility, there were frequent explosions within the furnace until the operators learned to control the operation of the pug mill more closely and thus blend dired and wet material before feeding the cage mill of the dryer circuit. The plant operator did not believe that this pug mill operation could be automated and felt that is was a critical element in the system. The plant also experienced dryer-fan unbalance problems because tar vapors condensed on the fan blades. Odor-emission problems were resolved by preheating the dryer vent gases and passing them into the hot zone of the furnace. Odors emanating from the vacuum filter area were deodorized by ducting the foul gases from the vacuum pumps into the incinerators.

The Raymond system of drying sludge is certainly a feasible one, and the system hardware is commercially available. A flash-drying system, however, requires careful operator control. It is our conclusion that most of the failures and abandonments of the system result from poor application of the principle and from the use of unskilled, inadequate operators.

Rüb[36] has reported on the Keller-Peukert system, which is similar to the Raymond system except that hot air is used and the spent dryer air is introduced into the MMR windbox under the grates, thus serving as both drying and combustion air. While this system appears advantageous, Matsumoto[37] has pointed out the problems of early ignition of refuse on the drying-grate section.

This technique is therefore judged acceptable for further study.

Technique 7: Co-Incineration by Pyrolysis

Seven pyrolysis systems were identified as being potentially capable of handling the co-incineration of MMR and MSS. Each of these systems is proprietary and in an early state of development. Union Carbide's prototype, full-scale Purox[38] system is undergoing a test program in South Charleston, West Virginia, and Union Carbide has not yet decided whether to offer the system commercially. Private discussions and communications with Union Carbide personnel indicate that their desk-top study on co-incineration of MMR and MSS shows that it is wholly feasible. The Purox system can be described as an oxygen-blown shaft furnace requiring the purchase of oxygen or the construction and operation of an oxygen plant along with the incinerator plant. The City of South Charleston has recieved an EPA grant to test co-incineration using the prototype "Purox" reactor at Union Carbide's South Charleston plant.

The Monsanto system,[40] accomplishing pyrolysis in a rotary kiln, is also in a prototype full-scale demonstration status. The installation in Baltimore, Maryland may be considered as having gone on line in January of 1975; again, the manufacturer has considered the co-incineration option.

Carborundum's Torrax system,[40] which was pilot-tested under EPA grant at Orchard Park, New York, has been deemed a commercial product by Carborundum as of midsummer, 1974. A Torrax furnace is being built in Luxemburg, and another has been sold in France. As of this writing, none has been sold in the United States. Tests charging sludge to the furnace were conducted at Orchard Park, with reputed success. The Torrax system may be termed an air-blown shaft furnace.

The Garrett system,[40] planned for San Diego, California, accomplishes pyrolysis in a flash pyrolysis reactor. Ground has been broken for the full-scale prototype unit, but it will not be operational for some time.

The Titan Thermogen system may be described as an air-blown shaft furnace. At present, the manufacturer is not marketing the system, and the sole installation is at the National Secrity Agency in Ft. Meade, Maryland. Problems include solidification of the material in the furnace, which shuts down the operation.

The very early developmental state of all of the pyrolysis units makes it very difficult to assess the ultimate feasibility, except as concerns some very basic parameters. As is typical of pyrolysis systems, they operate with less than the stoichiometric quantity of air and produce an off-gas or oil that, after proper cleansing, may be used as a fuel. They produce either a char or a slag residue, depending on the system considered. In the case of Purox, Torrax, and Titan Thermogen, the furnaces produce a molten slag, which when fritted in water produces a chemically inert black sand. This is potentially useful as an aggregate in road building, or can be safely disposed of in a landfill. The Monsanto system produces a char, and the flash-reactor Garrett system probably produces a fine inert ash.

The Purox system, even with the penalty of the attendant oxygen plant, is an attractive system because the use of oxygen obviates the need to heat copious quantities of relatively inert nitrogen; this represents a thermal economy that cannot be achieved with an air system. The Torrax system uses a portion of the pyrolysis off-gases to preheat the air blown into the shaft furnace. The pyrolysis technique has sufficient promise to be included among the candidates warranting further study; the technological obstacles encountered to date probably will be overcome in one or more of these systems.

None of the co-incineration techniques identified that did not fit within the techniques already discussed was sufficiently interesting to warrant establishing another technique category.

Summary

The state-of-the-art of co-incineration is poor, and none of the plants practicing the air can be considered an outstanding success. The major recent interest has been abroad, but this may be waning. One European contact states, "I do admit that there was quite a loud-spoken interest in sludge incineration a few years ago. The interest has died off since then, however. It is highly doubtful that there will be any further installations." Nevertheless, Lurgi reports orders for a number of new units. Perhaps the answer is that there are too many approaches and lack of a consensus on the best system for the future.

We have subjected the various techniques to a subjective analysis, with the following results (a low ranking is best):

Technique	Rank
1. Solid waste incinerator	2
2. Multiple-hearth furnace	4
3. Fluidized-bed incinerator	5
4. Waste heat evaporation	3
5. Spray injection	1
6. Flash evaporation	3
7. Pyrolysis	1

Twelve factors were considered, each on a scale of zero to four. Each technique was analyzed both by applying equal weight to each factor, and by weighting the factors from one to five. These factors were considered:

- The status of the technique--ranging from failure to proven.
- The need for sludge preprocessing--ranging from intensive to simple sedimentation.
- The need for refuse preprocessing--ranging from intensive plus cleansing to none.
- The emission potential--ranging from extreme to minimal.

- The odor potential--ranging from extreme to minimal.
- The excess air required--ranging from high to low.
- Specific capacity--ranging from minimal to optimal.
- Size limitations--ranging from very small to very large.
- Potential explosion hazards--ranging from probable to none.
- The permissible ratio of sludge to refuse--ranging from marginal to excellent.
- Capital cost--ranging from the most to the least.
- Required ancillary equipment--ranging from the most to the least.

Two of our principal investigators performed the analysis independently, and their rankings (weighted and unweighted) were averaged to yield the final ranking. Four co-incineration approaches were then selected for further study:

Co-Incineration System	Probable Approach
Pyrolysis Furnace (Technique 7)	Either the Purox or Torrax Shaft Furnace.
Indirect-Contact Sludge Drying (Techniques 4 & 6)	A grate-fired steam-generating incinerator with a thermal screw type of sludge dryer.
Direct-Contact Sludge Drying (Techniques 4 & 6)	A grate-fired refractory-wall incinerator with rotary sludge dryer.
Multiple-Hearth Furnace (Technique 2)	A MHF with the sludge and shredded-cleaned refuse fed to the top of the furnace.

Each of the prime recommendations also identifies a specific approach, i.e., Purox, Thermal Screw, Rotary Dryer. We consider the systems as firm recommendations and the specific approaches as tentative selections subject to further study.

Pyrolysis (Technique 7) ranks high because the sub-stoichiometric combustion better utilizes the available heat. The Purox system, using oxygen, is particularly advantageous since the nitrogen in the air need not be heated, and because better control of slagging is theoretically possible. Another advantage is the fuel gas produced, which can be used to produce steam in conventional steam generators. The disadvantages are the developmental stage of this method and the need for an oxygen supply. The Torrax system, which uses preheated air, is an alternative to Purox and has the advantage of being commercially available, with one installation being constructed and another sold.

Techniques 4 and 6 ranked third but have been selected because once sludge drying has been taken as necessary it is clearly desirable to make the sludge drying step controllable. Both direct- and indirect-contact drying are technically feasible and adaptable to a wide range of MMR furnace designs (see Table 2). Either technique can be used with raw or prepared refuse, with the dried sludge added to the MMR or burned in suspension. The thermal-screw and rotary-dryer approaches are suggested as appropriate devices.

Technique 2 has been selected over Technique 3, principally because there are several multiple-hearth furnaces in use abroad on co-incineration of MSS and MMR.

Omitted from our recommended list are Techniques 1 and 5, for which dewatered sludge is added to the refuse fed or thickened sludge is injected into the furnace. These techniques subjectively rank first or second largely because they are simple systems representing a very direct approach to co-incineration; however, both are technologically supect. Technique 1 has failed in the past because of sludge-burning problems. Techniques for sludge dispersion, such as high-speed disk atomization, high-velocity air jet atomization, sonic atomization, combined shredding of sludge and refuse, blending sludge with dry ash, and sludge comminution before injection are all techniques which might provide solutions to the sludge dispersion problem. Technique 5 failed at Altrincham, and any solution would require test confirmation to lend credence to the method. Technique 5 may very well succeed, as in the proposed Dickerson Station, but would constitute a special case applicable only to utility or large industrial furnaces fired primarily by a fossil fuel.

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SECTION V

FEASIBILITY STUDY

APPROACH TO EVALUATION

It is apparent from the state-of-the-art assessment that co-burning of wet sludge and refuse in a conventional, grate-fired incinerator is not feasible. There is little question, however, that dry sludge is a readily combustible material which could be easily co-burned with refuse. Two of the four techniques discussed in this section, therefore, place heavy emphasis on predrying the sludge in equipment external to the refuse incinerator. Both direct- and indirect-contact drying are explored. The engineering principles defining these unit operations are well established, and the drying circuits are combined with conventional refractory or steam-generating incinerators, whose design and operational basis are also highly developed.

Two additional co-incineration techniques (not involving sludge predrying) are examined. Multiple hearth (M.H.) co-incineration and pyrolysis co-incineration combine wet sludge and refuse before feeding to the combustion units. Although the sludge drying is preliminary to actual combustion, it occurs within the incinerator (together with drying of the refuse). In neither case, however, is wet sludge fed directly to the combustion zone of the unit; instead, the sludge moves through a predrying zone, within the unit, before entering the active combustion zone.

Sludge Drying

Sludge drying, either external or internal, plays a significant role in co-incineration. The failure of many attempts to burn wet sludge clearly indicates that some form of sludge predrying is necessary for effective co-incineration.

The emphasis in this feasibility section is therefore placed on the thermodynamics of sludge drying and its relationship to the combustion of dry sludge and refuse. A feasible energy balance is a minimum requirement in the establishment of the viability of a co-incineration process. Before evaluating any other parameters affecting the feasibility of co-incineration, the availability of sufficient energy to dry the sludge must be determined.

For practicality, not only must sufficient energy be available, but also the energy must be available in such a form that the processes and equipment for heat transfer fall within reasonable bounds of size and cost-effectiveness. It would be easy to demonstrate that sufficient energy for sludge drying is available from many sources, including non-combustion sources such as solar or nuclear energy. Sludge drying using heat from such sources is thermodynamically feasible, but is not currently practical with existing hardware. Thus, energy transfer and transport also play a major role in determining the feasibility of a co-incineration process.

Refuse-to-Sludge Ratio

Any attempt at an energy balance must be based on an appropriate mass balance. It is clear that the refuse-to-sludge ratio is a major factor affecting co-incineration feasibility. If refuse is considered to be an auxiliary fuel (to provide the additional heat necessary to dry the sludge), it is obvious that sufficient refuse could be fired to make a feasible energy balance. On a small scale, such an approach appears valid. However, although available in large quantities, refuse as a fuel is limited; jurisdictional boundaries and transportation costs for sludge and refuse play a critical role in limiting the quantity of fuel-refuse available for co-incineration at a single location (See Section VIII).

Since this study deals primarily with domestic sludge and refuse, it is appropriate to base the evaluation on equivalent-population quantities of sludge and refuse, for these are precisely the quantities that are available. These quantities and the expected composition of sludge and refuse are developed in Appendices C and D. The basic quantities are refuse--1.24 kg (2.74 lb) per capita per day; sludge--0.09 kg (0.2 lb) per capita per day (dry solids).

An analysis of co-incineration feasibility based on population equivalents of sludge and refuse is likely to lead to a conservative estimate of fuel (refuse) availability, because it considers only domestic sources of refuse. Both commercial/institutional and industrial refuse also require disposal in any specific area. Many municipalities will not accept refuse from industrial sources, but commercial/institutional refuse generally is accepted at the municipal incinerator, and would tend to increase the heat available for sludge drying in a co-incineration facility.

In addition to providing sufficient heat to dry and ignite the sludge, the refuse fuel must provide sufficient heat to raise the temperature of combustion products to a temperature which insures complete oxidation of organic materials; a flue gas temperature of 760°C (1,400°F) is generally considered the minimum necessary for destruction of organic materials, elimination of odor and minimum emission of carbon monoxide. Consequently, a feasible co-incineration system must produce a flue gas temperature of at least 760°C (1,400°F).

Excess Air

A major factor influencing furnace and flue gas temperature is the excess air encountered in refuse incineration. Excess air insures sufficient oxygen to complete combustion, and provides some cooling to the furnace system. Typical refractory incinerators are operated with excess air levels of 150 to 250 percent, although levels as high as 600 percent are encountered in older furnaces in which air infiltration often is high. Steam-generating incinerators of the water-wall configuration operate at excess air levels of 50-150 percent, because steam generation removes heat normally carried off in the higher flue-gas volumes of refractory incinerators. Multiple-hearth furnaces are designed for excess air rates of 75 percent and generally operate in the range of 50-100 percent excess air. A higher percentage of excess air will be required when co-burning sludge with refuse in such equipment, and a range of 75-150 percent has been suggested by equipment manufacturers. Pyrolysis equipment, by definition, uses less than stoichiometric quantities of combustion air; this lesser amount of air provides partial combustion to produce heat for pyrolysis of the remaining refuse and sludge volatiles. Combustion air requirements for pyrolysis systems are determined by factors other than the temperature considerations applicable to the other types of co-incineration systems.

One of the major objectives of this study is the reduction or elimination of auxiliary fuel requirements in sludge incineration by the substitution of refuse as the source of heat. While elimination of fuel requirements would be the ideal, several factors will require the continued use of small quantities of auxiliary fuel. Both sludge and refuse are highly variable materials; in particular, moisture variations in sludge can vary from hour to hour, and moisture in refuse is often variable, depending on weather conditions. The response time of an incinerator, with its large mass of refractory, is very slow; consequently, some auxiliary fuel will be necessary to provide system control.

Miscellaneous Factors

A number of other factors may have impact, to various degrees, on the feasibility of co-incineration:

Plant Size
Incinerator/Treatment Plant Location
Population
Growth
Administration
Reliability
Maintenance
Air Pollution
Water Pollution
Ultimate Disposal

These factors are discussed in this section on technical feasibility and in Section VII--Economic Considerations and Section VIII--Circumstances Having Impact on Feasibility.

Heat and Material Balance

Since thermodynamics plays such a major role in determining the feasibility of co-incineration, the heat and material balances for the four chosen techniques have been studied in detail. A Weston-developed incineration computer model is used to predict the operating parameters of the system. The ultimate analyses of sludge and refuse (Table 3) are input to the computer, along with the capacity and the sludge-to-refuse ratio. Flue-gas enthalpy and composition are calculated for a range of excess air rates. The program also predicts steam-generation rates, gas-conditioning tower parameters, and saturation conditions of the combustion products.

TABLE 3. REFUSE AND SLUDGE COMPOSITION
(Percent by Weight)

		Refuse (as delivered)	Sludge (Dry, Volatile Fraction)
Carbon	(%)	24.7	55.0
Hydrogen	(%)	2.6	5.9
Oxygen	(%)	21.8	35.0
Inerts	(%)	22.0	---
Water	(%)	28.0	---
Nitrogen	(%)	0.45	3.13
Chlorine	(%)	0.30	0.0
Sulfur	(%)	0.15	0.93
HHV	$\frac{\text{Btu}}{\text{lb}}$	4,500	10,000
	$\frac{\text{kg-cal}}{\text{kg}}$	2,500	5,600

The co-incineration heat balance can best be studied as a system of independent variables: sludge-to-refuse ratio, sludge solids (assuming fixed refuse moisture), and excess air; flue-gas temperature is taken as the dependent variable. It is difficult to work with and graphically represent a four-variable system. As noted, the sludge-to-refuse ratio was fixed at an equivalent population basis. The graphical data presented in the following sections thus represent only two independent variables: excess air and sludge solids (4 percent, 20 percent, and 45 percent representing the three common dewatering techniques, as discussed in Appendix C).

In co-incineration practice, however, there may be cases where equivalent quantities are not available or where it is necessary to determine the minimum quantity of refuse necessary to support co-incineration. In analysis of such cases, one should note that dry sludge and dry refuse have essentially the same heating value. Thus, even though the composition of the composite wastes will vary with various sludge/refuse ratios, this variation will not materially affect the thermodynamics of the system. The refuse (dry basis)-to-sludge (dry basis)-ratio can, therefore, be eliminated as a significant variable. The two remaining independent variables then become excess air and total moisture in the feed.

By assuming a typical refuse moisture content (note that this is not a variable which can be controlled), it is possible to determine the minimum refuse quantity necessary to support co-incineration (i.e. maintain a final flue-gas temperature at any given excess air rate, from data provided in the following subsections). Given the maximum quantity of refuse available, it is also possible to determine the minimum sludge solids concentration of the maximum sludge rate acceptable for successful co-incineration. These quantities will be of interest where wastewater treatment is regionalized but refuse collection is not, or where high refuse-hauling costs tend to preclude transportation of all refuse to a co-incineration disposal site. The data will also be useful in specifying the type of sludge-dewatering equipment necessary for a co-incineration facility.

DIRECT-DRYING CO-INCINERATION

Direct-contact drying was chosen for detailed study because this technique has been successfully demonstrated in sewage-sludge drying service and because it is a well-established drying process widely practiced in many forms in the industrial sector. Figure 4, a block flow diagram, shows the material flows for such a process. Sludge is predried by contact with the incinerator flue-gas. Then the dried sludge and moisture-laden gases go to the combustion zone of the incinerator, where the volatile portion of the sludge solids and any odorous materials in the moisture-laden gases are destroyed by high-temperature oxidation.

Direct-contact drying implies intimate contact between the hot drying medium and the material to be dried, with no barrier between the two. In applications involving the drying of solids, hot gases (generally heated air or combustion products) are passed over, around, or through the solids to be dried. Contact between the hot gases and the solids is good. Inlet temperatures are high, thus increasing the driving force for evaporation. High heat-transfer rates and high inlet temperature, 150°-1,650°C (300-3,000°F), account for the generally favorable efficiency of direct drying of solids, 16-96 kg water/cu m dryer capacity/hr (1-6 lb water/cu ft dryer capacity/hr). However, the gas-solids contact often results in contamination of the gases with pollutants (including particulate and vapors), and the consequent need for pollution control equipment such as electrostatic precipitators, baghouses, or scrubbers.

Direct drying is widely used in industry. Common dryer types include rotary dryers, spray dryers, flash dryers, and fluid-bed dryers.

Rotary Dryers

Rotary dryers and kilns are widely used in industrial applications such as drying, dehydrating, and calcining. The dryer generally consists of a large, horizontal, cylindrical drum, rotating at slow speeds on its axis, with hot gases passing through the shell in either a concurrent or counter-current flow. In many high-temperature operations, fuel is fired directly into the dryer, with combustion taking place within the dryer shell; in such cases, the dryer shell is often lined with refractory.

Lifting flights are generally installed in the dryer to provide increased gas/solids contact by lifting and then dropping the solids through the gas stream. The lifting flights and the rotating action of the drum provide gentle agitation, and prevent the formation of extremely small particles. The agitation also provides a degree of back mixing, resulting in a more uniform dry

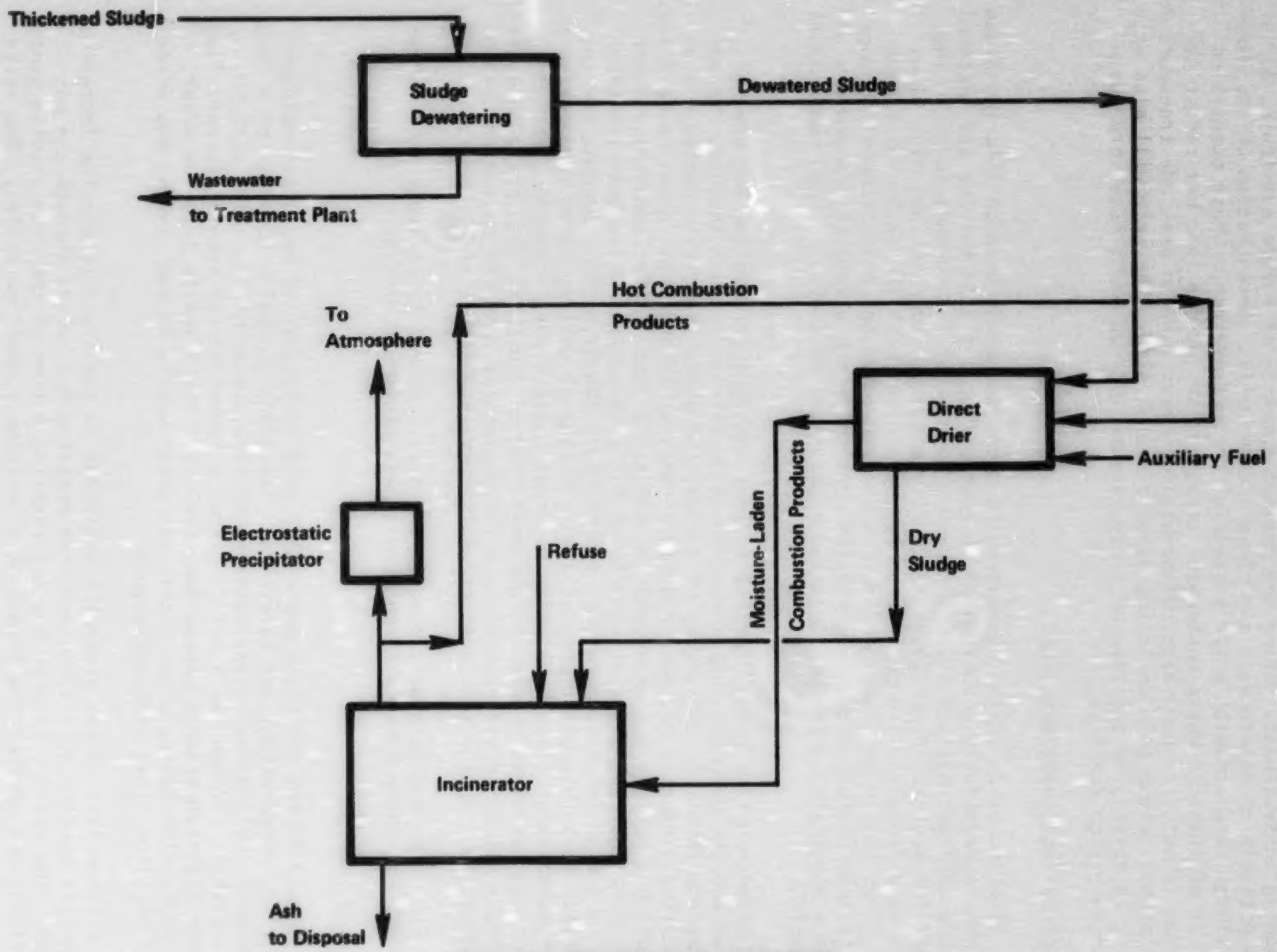

Thickened Sludge
Sludge Dewatering
Dewatered Sludge
Wastewater
to Treatment Plant
Hot Combustion
Products
To
Atmosphere
Direct
Drier
Auxiliary Fuel
Electrostatic
Precipitator
Refuse
Moisture-Laden
Combustion Products
Dry
Sludge
Incinerator
Ash
to Disposal

Figure 4. Direct Dryer Co-Incineration Schematic Flow Sheet.

product. The effective agitation and the fact that the means of solids injection into the dryer generally is not critical make the rotary dryer particularly suitable for heavy sludges. With sticky solids, however, rotary dryers perform poorly. Such materials deposit on the walls of the dryer and dry there; after extended periods, the deposits can significantly reduce the inside diameter of the dryer, resulting in high gas velocities and poor performance.

Although the throughput of a rotary dryer generally is high, the residence time is long. This extended residence time tends to reduce the effects of variations in sludge concentrations and in the temperature and the volume of the incinerator off-gas. The response time of a rotary dryer, however, is slow, because of the large mass of solids. It can be improved by providing direct fuel firing at the hot gas inlet.

Spray Dryers

Spray dryers normally consist of large vertical towers into which the material to be dried is sprayed. It is always necessary to break the material into small particles or fine droplets, thus increasing the surface area and reducing drying time. High-pressure spray dual-fluid spray, and high-speed disc atomization are commonly used. The heat input in spray dryers is pre-heated air or combustion products. Hot gases enter the dryer in a variety of configurations, but flow is generally co-current. Design parameters of gas flow and temperature can be varied through only a narrow range. Residence time in the spray dryer is generally very short, with dried solids separated from the hot gases immediately after leaving the dryer, normally in mechanical collectors. More efficient secondary pollution control equipment is also required, to remove the small particles which remain.

Problems associated with the relatively short retention time in the dryer and with atomizing the thickened sludges are considered major disadvantages to the use of spray dryers in sludge co-incineration.

Flash Dryers

Flash drying, as applied to sludge, is similar to spray drying. In most instances, however, flash drying combines the drying with sludge cake size reduction (by mechanical comminution), thereby eliminating the critical atomization step encountered in spray drying. The solids are generally injected into a high-velocity gas stream and pneumatically conveyed to a mill for size reduction. (Flash dryers are often referred to as pneumatic-conveyor dryers.) Hammer and cage mills have been widely used for this purpose. With heavy solids (such as filter cakes or slurries), the solids may be injected directly into the mill. Drying occurs in the mill and during the transfer to the solids-separating equipment.

As with spray dryers, residence time is short and operating conditions must be reasonably stable for satisfactory performance. A major disadvantage of flash drying is the fine, dusty powder which results. The dust is difficult to collect and control, and may constitute an explosion hazard when organic materials are dried. Despite this disadvantage, flash drying has been one of the more popular sludge-drying processes. The CE/Raymond flash dryer, for instance, has been used in many sewage treatment plants to dry thickened sludges. In most cases, the dry sludge has been collected and distributed as fertilizer or soil conditioner, rather than incinerated.

Fluid-Bed Dryers

In fluid-bed systems, natural gravitational forces acting on the solids are balanced by the drag force of rising gases. Under proper operating conditions, the net solids flow is zero, and a dense-phase fluidized bed occurs.

As the solids dry, density is reduced, and the dry solids are discharged overhead with the drying gases. Fluid-bed dryers are limited by the velocity of the air or gas stream fluidizing the solids. Once the air volume is specified, a limit is placed on the heat transported into the dryer, and control of the dryer becomes difficult. To provide a heat sink within the dryer, a second solid (generaly sand) is often added. The particle size of the sand must be chosen carefully to insure fluid-bed operation. The bed becomes heated to the temperature of the incoming gases and serves as a reservoir of heat to decrease the variations in other operating parameters.

The dried solids are separated from the gas stream by mechanical collectors. Because of the high velocities necessary to maintain the fluid bed, the gas stream is often recirculated, with removal of a bleed stream as an integral part of the operations. Make-up air and heat are added before the stream is returned to the dryer.

The major problem experienced with fluid-bed sludge dryers has been the tendency for large lumps of dense sludge to drop through the sand bed. (The smaller sludge particles are buoyed up by the sand and fluidizing gas and dry rapidly.) It is possible that blending wet sludge with predried material would improve the performance of fluid-bed driers, but back mixing the dry sludge with incoming wet sludge has not yet been evaluated full scale.

The advantages of fluid-bed drying include no internal moving parts, excellent mixing, good heat transfer, and close control of average moisture content of the product. At present, however, problems with sludge feeding (e.g. large lumps of cake dropping through the bed) and with the variations experienced with thickened and dewatered sludge limit the uses of this drying technique.

Heat and Material Balance

Based on the foregoing considerations, a rotary dryer was selected to represent the direct-drying technique. Before a heat and material balance can be developed, basic relationships must be established. Sludge and refuse quantities and characteristics, i.e. 0.09 kg (0.2 lb)/capita/day dry weight for sludge and 1.24 kg (2.74 lb)/capita/day at 28 percent moisture are based on those appearing in Appendices C and D, and on an equivalent-population ratio of sludge to refuse. Sludge drying depends on refuse combustion, but refuse can be incinerated without drying any sludge. Consequently, there may be occasions when the sludge drying rate may have to be increased temporarily to make up for dryer down-time, and the effect of 20 percent excess (above equivalent population) sludge on process thermodynamics was evaluated to assess such conditions. The minimum flue gas temperature suitable for odor destruction is 760°C (1,400°F).

To establish a heat balance, the Weston co-incineration model was run at three sludge-moisture levels: 4 percent solids, representing thickened sludge; 20 percent solids, representing vacuum-filtered sludge; and 45 percent solids, representing pressure-filtered sludge. Refuse in all cases was assumed to contain 28 percent moisture. The input and output of the INCIN program run for direct-dryer co-incineration appear in Table 4; the calculated results also appear in Figure 5.

TABLE 4. INPUT AND OUTPUT OF ANALYSIS OF DIRECT DRYER CO-INCINERATION ALTERNATIVE BY INCIN PROGRAM -- EQUIVALENT SLUDGE/REFUSE PRODUCTION

Refuse %	Sludge %	Sludge Solids %	Total Moisture %	Furnace Outlet Temp. (°F) Excess Air (%) 0	100	200	300	400
35	65	4	72	1,010	780	640	540	470
71	29	20	43	2,520	1,750	1,350	1,100	930
84	16	45	32	2,900	1,950	1,480	1,200	1,020

With an excess air rate of 150 percent (the minimum acceptable for satisfactory operation of a refractory incinerator) co-incineration will achieve the desired flue-gas temperature of 760°C (1,400°F) only if the overall moisture content of the feed (sludge plus refuse) is 50 percent or less. Since refuse moisture depends on factors beyond the control of the incinerator operator or designer, control of sludge moisture is the only approach available for control of the overall moisture content of the mixed feed. A moisture content of 50 percent in a mixed feed containing typical refuse requires a sludge containing 13.5 percent solids. Vacuum-filtered sludge generally contains 20 percent solids; when combined with typical refuse, a mixed feed with a moisture content of 43 percent is produced, well within the feasible operating range for co-incineration. With such a feed, the incinerator could operate at 200 percent excess air and still maintain an acceptable flue-gas temperature. Thus, the incremental solids in the sludge (over the minimum required) provides a margin of safety for overcoming fluctuations in refuse or sludge moisture.

If the sludge is pressure-filtered (to 45 percent solids), the excess air rate can be as high as 250 percent without adverse effect. However, pressure filtration often involves the addition of significant quantities of inert filter aid, which increases the amount of residue requiring disposal. Consequently, there is little justification for increasing the solids content of the sludge to 45 percent.

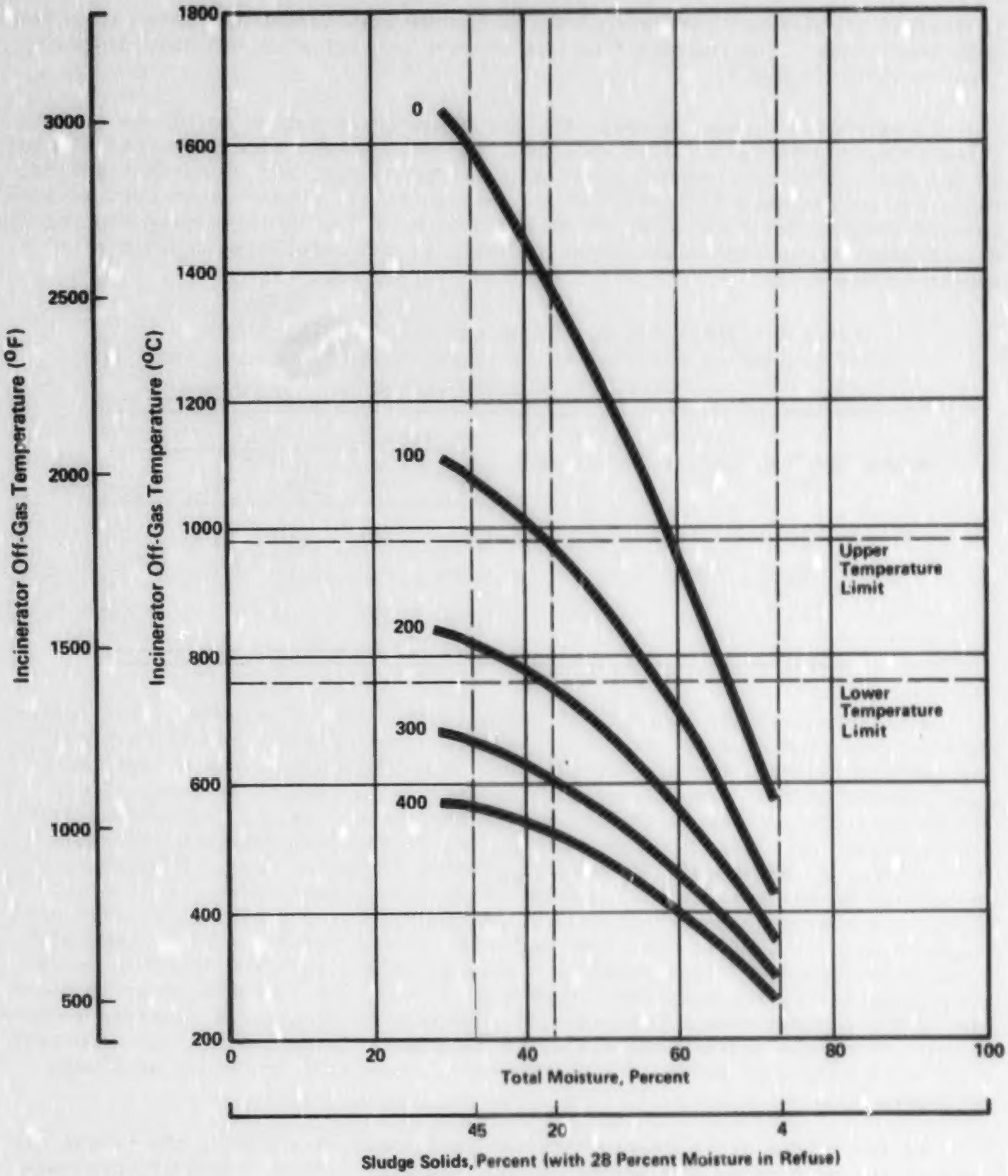


Figure 5. Direct Dryer Co-Incineration Gas Temperature (Equivalent Population)

Based on available heat in the incinerator flue-gas, 760°-980°C (1,400-1,800°F), approximately 10 to 15 percent of the combustion products will be directed to the dryer. To overcome the variation in flue-gas temperature and to provide some cooling so that metal duct work can be used, it is advisable to dilute the dryer gas with sufficient ambient air to reduce the temperature to about 650°C (1,200°F). This should be compensated for by further reducing the excess air in the incinerator, since all gases passing through the dryer are returned to the furnace's combustion zone for destruction of odorous gases. The gases returned from the dryer should enter the incinerator through the high-pressure overfire-air supply system; this will minimize the total air requirement as well as provide good mixing in the active combustion zone.

The dryer off-gas could be returned with the underfire air (through the wind box under the grate), but excessive condensation may be experienced, and this approach is not recommended. In some plants (Ansonia, Connecticut), the return gas is simply ducted into the incinerator furnace, but such a configuration makes complete mixing of return gas and furnace gas more difficult and may result in poor odor control.

As indicated in Figure 4, dry sludge solids (at 15 percent moisture) are conveyed to the incinerator and blown over the active combustion zone; burning will be in suspension. In addition to reducing the weight and volume of sludge solids, combustion of the sludge solids provides additional heat for dryer operation.

The input and output of the INCIN program run for direct-dryer coincineration (120 percent of equivalent value) appear in Table 5. The calculated results also appear in Figure 6. Figure 6 is a representation of the same sludge and refuse as in Figure 5, except that the sludge feed rate has been increased by 20 percent beyond the "equivalent population" rate. As expected, the curve falls somewhat below that of the equivalent-population ratio of sludge and refuse. However, results of combustion modeling indicate that co-incineration remains feasible at excess air rates of up to 175 percent for 20%-solids sludge and at 225 percent excess air for 45%-solids sludge.

TABLE 5. INPUT AND OUTPUT OF ANALYSIS OF DIRECT DRYER CO-INCINERATION ALTERNATIVE BY INCIN PROGRAM -- SLUDGE/REFUSE RATES AT 120 PERCENT OF EQUIVALENT VALUE

Refuse %	Sludge %	Sludge Solids %	Total Moisture %	Furnace Outlet Temp. (°F) Excess Air (%) 0	100	200	300	400
67	33	20	45	2,440	1,700	1,310	1,070	910
81	19	45	32	2,870	1,940	1,470	1,200	1,010

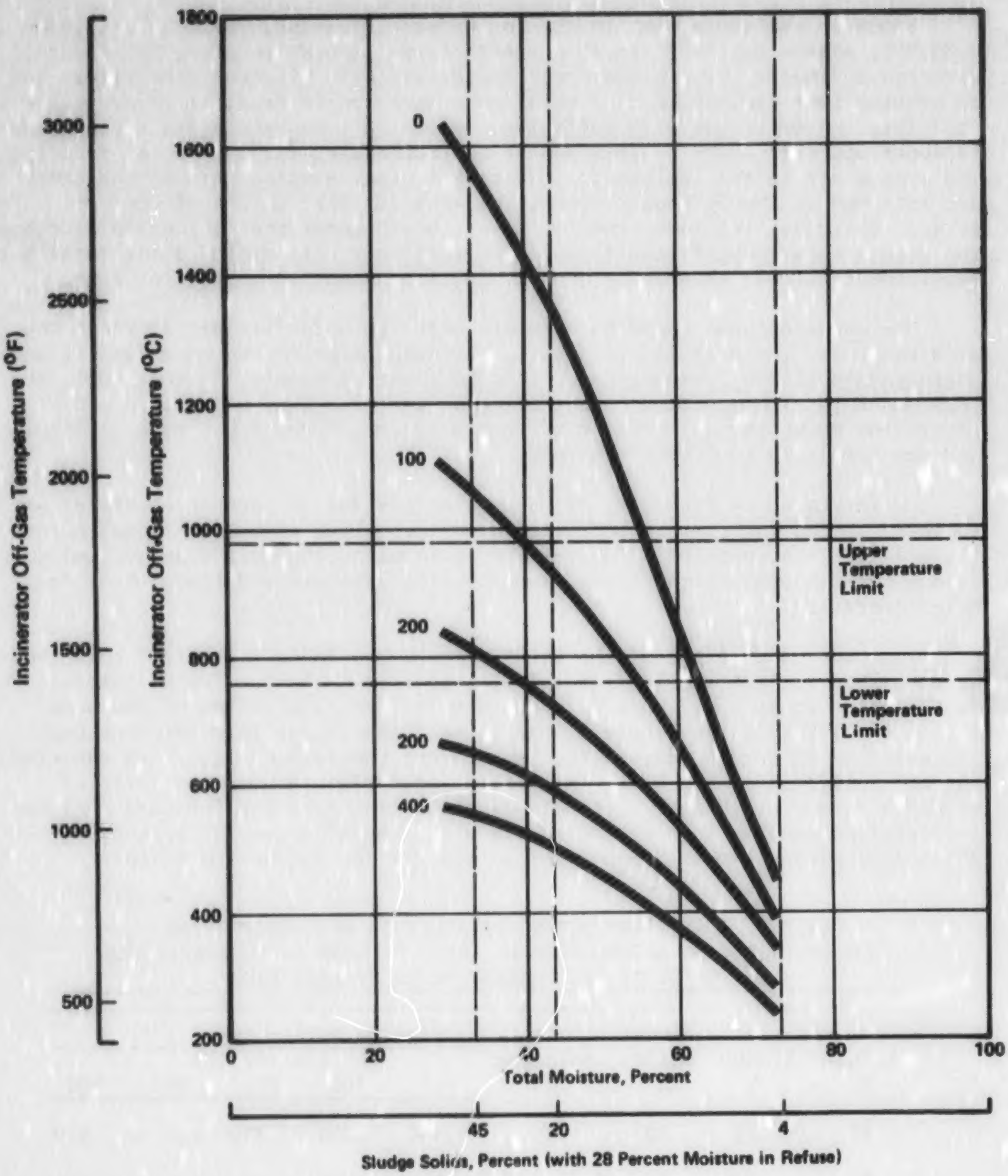


Figure 6. Direct Dryer Co-Incineration
Gas Temperature (20% excess sludge).

Dryer Design

The heat balance data indicate that co-incineration is thermodynamically feasible. However, the heat must be conveyed to the dryer and transferred to the solids (with resulting evaporation) efficiently if direct drying is to be a practical co-incineration technique.

To determine if equipment size is reasonable and to provide a basis for later cost estimates, some preliminary design data are necessary. In a direct-drying system, hot combustion gases are drawn from the incinerator at a temperature close to the incinerator flue-gas temperature, 760°-980°C (1,400-1,800°F). Refractory-lined ductwork is necessary at the furnace withdrawal point.

If the entire ductwork and dryer system is refractory-lined, no reduction in temperature will be required for system integrity. However, excessively high inlet-gas temperatures could result in ignition or explosion of the sludge in the dryer. If steel equipment is used for ductwork and dryer components, the temperature of the inlet gas will have to be reduced to about 650°C (1,200°F) by dilution with ambient air. Since dryer off-gas will be returned to the combustion air system, such an approach will not increase the overall furnace excess air. A water spray system could also be used, but would unnecessarily increase humidity throughout the gas-handling system.

The dryer should be operated on a co-current flow basis. This minimizes the possibility of fire hazard in the dryer by contacting the hottest gases with the wettest sludge. Since there is no need to dry the sludge completely, maintaining a high temperature differential at the dry end, by using counter-current flow, is unnecessary. In fact, it is generally undesirable to dry the sludge solids completely, because dry sludge solids create a flammability and dust problem. A final, average sludge moisture content of 15 percent is generally sufficient to minimize dusting and the resultant explosion hazard.

In the design of a dryer system, the temperature and flow rate of the hot inlet gases, the inlet and outlet sludge moisture content, and the outlet gas temperatures must all be specified. The inlet temperature for unlined equipment is generally about 650°C (1,200°F), and the outlet temperature from the dryer should be at least 150°C (300°F) to minimize condensation. The gas flow, along with inlet and outlet temperatures, determines the capacity of the dryer. The shell diameter is determined by gas-velocity considerations; velocities of 60 to 76 m/min (200 to 250 ft/min), at mean gas temperature, are typical. These velocities provide adequate turbulence, yet prevent undue carry-over of solids. The dryer length and pitch are determined by residence-time requirements. (A residence time of at least 60 minutes is recommended.) Dryer pitch generally is approximately 1 cm/m (1/8 in./ft).

Dryer rpm will also affect the drying rate and residence time, and rotation speeds of 3-5 rpm are typical. For effective drying, the shell should also be equipped with lifting flights to tumble the sludge through the hot gas more effectively.

Auxiliary fuel, as required to maintain design operating conditions, should be fired at the inlet end of the dryer. Experience indicates that firing auxiliary fuel, at a level of 20 percent of the heat necessary to dry the sludge, has little effect on the incinerator outlet temperature. However, a major portion of the auxiliary heat is utilized in sludge drying, rather than in heating the large quantities of excess air and combustion products in the incinerator.

After the sludge is dried, the moist dryer gas should be returned to the incinerator. At this point, the temperature is elevated to a minimum of 760°C (1,400°F), at which point all odorous material is destroyed. A cyclone, in the dryer gas return line before the induced-draft fan, is generally needed to remove particulate material carried over in the gas stream.

A portion of the dried sludge is separated and premixed with incoming wet sludge solids. Premixing of dry and wet sludge minimizes variations in dryer inlet moisture content and also reduces handling problems with the wet sludge. Sufficient dry sludge should be back-mixed with incoming wet sludge so that the dryer inlet moisture content is approximately 50 percent. Good agitation will be necessary in the mixer to insure reasonable distribution of the dry sludge and to break up the wet sludge cake.

Effect of Size

Rotary dryers are available in a wide range of sizes from 0.15 m (6 in.) to over 7 m (24 ft) in diameter. On a practical basis, however, dryer size is generally limited to 3.7 to 4.3 m (12-14 ft) in diameter (outside), which is the largest diameter which can be shop-fabricated and transported over the road. If this does not provide sufficient capacity, multiple dryers should be used. A dryer 3.7 m (12') in diameter will dry approximately 180 metric tons (200 tons) per day of 20%-solids sludge, corresponding to a community of about 400,000. Thus, dryer size is not a major determinant of technical feasibility.

The other major part of this co-incineration system is the incinerator itself. Again, with the use of additional units, there is no maximum overall plant size. The smallest incinerator generally constructed has a capacity of about 230 metric tons (250 tons) per day, which corresponds to the refuse-disposal requirements of a community of 150,000 people.

Although it is not necessary to operate an incinerator 24 hours per day, intermittent operation of a co-incineration plant, with the dryer described, may significantly increase auxiliary fuel consumption, because of temperature control requirements and the heat-up time of the incinerator. If the incinerator must be started up daily, at least one hour of start-up time, during which the dryer cannot be operated without auxiliary fuel firing, will be required. The incinerator flue gas must reach a temperature of at least 760°C (1,400°F) before the dryer can be placed in operation.

Based on size considerations, co-incineration involving a refractory incinerator and a rotary dryer is feasible for municipalities serving 150,000 or more. The major design consideration will be the incinerator size rather than the dryer size. For communities of less than 150,000, a direct-dryer/co-incineration plant could be constructed, but economics would be adversely affected.

INDIRECT-DRYING CO-INCINERATION

Indirect-contact drying is the second of the two pre-drying processes evaluated for technical feasibility. While there have been some successful sludge-drying processes demonstrated in Europe utilizing this technique, the process as described here (and presented as a block flow diagram in Figure 7) has never been practiced. There are several potential advantages to this type of drying process:

1. Heat transport to the dryer should be more efficient than in direct drying.
2. The total energy available for sludge-moisture evaporation should be greater than in direct drying.
3. Equipment size should be considerably smaller.
4. There may also be sufficient heat available at equivalent-population sludge-to-refuse ratio to make the sale of excess energy (or its use within the plant) feasible.

In an indirect heat-transfer application, there is no contact between the materials being heated and cooled; a heat-transfer surface provides a barrier which eliminates contact between the two materials. The most widely used indirect heat-transfer configuration is the shell-and-tube heat exchanger. With the presence of a barrier between the two materials, there is no contamination of the heat source by the materials being heated or dried. This fact is of significant importance in applications such as sludge drying, where all contaminated materials must be later incinerated or further treated in some way. The same barrier which prevents contamination of the heat transfer fluid also acts to impede heat transfer by adding additional resistance. However, it permits the use of a phase change in the heating fluid, with the recovery of latent heat. The use of a condensing fluid as the heat source maintains high temperatures uniformly over the entire heat-transfer surface, and permits the transport of large quantities of heat in a small mass of heat-transfer fluid.

In solids-drying applications employing indirect heat, the wet solids are distributed on or about the hot surface. Consequently, agitation of the solids is of major importance in obtaining good heat transfer. If solids are un-agitated, heat must pass through the solids by conduction and convection. Often, both the hot surface and the solids are in motion.

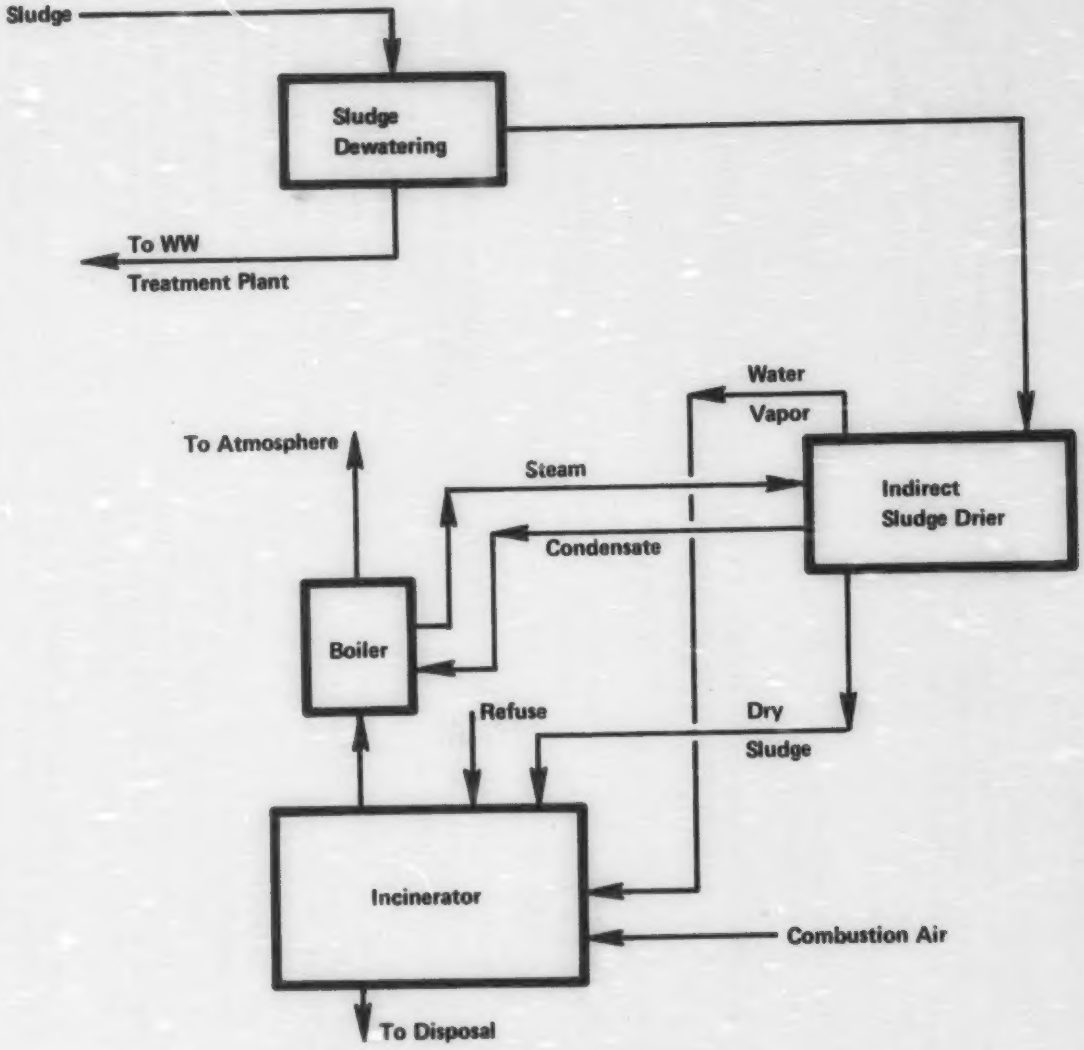

Sludge
Sludge Dewatering
To WW Treatment Plant
Water Vapor
To Atmosphere
Steam
Indirect Sludge Drier
Condensate
Boiler
Refuse
Dry Sludge
Incinerator
Combustion Air
To Disposal

Figure 7. Indirect Dryer Co-Incineration Schematic Flow Sheet.

The most common heating fluid is steam. Steam is relatively safe, provides a high latent heat, and is widely available from power and industrial boilers. High steam temperature is accompanied by high pressure, however, and this high pressure often becomes the limiting factor in the design of indirect heat-transfer equipment. The problem (of high pressure) can often be overcome by using non-aqueous heat-transfer fluids, which exert a lower vapor pressure than steam. Other media (hot water, condensate, hot air, or combustion products) can also be used in indirect heat-transfer applications. The steam or other fluid generally is not the actual source of the heat, but rather is merely a convenient method of conveying the heat from its source, generally some form of combustion, to the point of use. Particularly if the heat must be transferred over great distances, steam or other condensible fluids provide a more efficient means of conveying heat than the use of hot gases, such as combustion products. The use of steam also provides a convenient means of temperature control. Since steam temperature and pressure are directly related, the use of a pressure-reducing valve on the steam line can be used to control the temperature at the heat-transfer surface very accurately. In all further considerations in the ensuing discussion we have assumed that steam is the heat-transfer fluid.

In heat transfer applications, one measure of effectiveness is the overall heat-transfer coefficient U_o:

$$U_o, \frac{\text{cal}}{\text{sec sq cm } ^{o}\text{C}} \quad \frac{\text{Btu}}{\text{hr sq ft } ^{o}\text{F}}\Bigg),$$

with dimensions expressed as a ratio of energy transferred as related to time, surface area, and temperature. U_o is a measure of the heat passing from the hot material, through the barrier, and into the colder material. The higher the heat-transfer coefficient, the more effective the transfer will be. Consideration of the dimensions of U_o shows that an increase in the quantity of heat transferred can be obtained by extending the contact time, by increasing the temperature difference between the hot and cold materials, and/or by expanding the surface area involved. Typical U_o in solids-drying application, using steam as the heat source, range from 6.2 to 124 cal/sec sq cm ^{o}C (5 to 100 Btu/hr sq ft ^{o}F), depending on degree of agitation and moisture content of the solids.

Industrial application of indirect drying of solids is not as widespread as direct drying. In general, it is used in areas where the vapor being removed must be collected or controlled in some manner, where vacuum must be applied to reduce the drying temperature of the heat-sensitive solids, or in cases where steam is the only form of heat available. Indirect solids-drying equipment generally takes the form of jacketed and/or hollow-flight conveying equipment, wiped-surface dryers, twin-shell or jacketed rotary dryers, twin-cone or other enclosed containers, flakers, or deck or shelf dryers.

Jacketed and/or Hollow-Flight Dryers and Conveyors

Jacketed and/or hollow-flight dryers or screw conveyors are frequently used in heating, drying, and cooling solids. They can often perform the dual function of heat transfer and solids conveying in one piece of equipment, generally a horizontal, semi-circular trough with a jacket or coil to provide heat. Such equipment has one or more agitation devices (e.g. screw, flight, disc, paddle) rotating on the axis through the center of the trough. A significant degree of agitation is necessary to maintain reasonable heat transfer to the solids. Simple screw conveyors are notably poor in this regard, because increasing the speed reduces the residence time in the dryer, by moving the sludge rapidly through the system. U_o for this type of equipment ranges from 18.6 to 93 cal/sec sq cm °C (15-75 Btu/hr sq ft °F), depending on moisture content and degree of agitation.

The agitators, paddles, or flights should also be designed to minimize build-up on the walls of the dryer and on the agitator itself. Generally, baffles or ploughs should be provided between the flights to improve mixing and to break up any lumps which form. The rotating flights are often fitted with small paddles or similar projections to improve agitation and reduce fouling of the shell surface.

Significant increases in heat transfer can also be obtained if the rotor is hollow and fitted for steam heating. A hollow heated rotor often provides one to two times the heat-transfer area available in the shell.

Wiped-Surface Evaporators

Wiped- or scraped-surface evaporators or dryers find limited use in industrial applications for drying viscous liquids, pastes, or materials which tend to foul heat-transfer surfaces. They are most widely used in vacuum drying applications. Wiped-surface dryers have been used in Europe for partial drying of wastewater sludge. Such dryers consist of a small-diameter cylinder, jacketed for steam heating. A slowly rotating shaft on the axis of the evaporator moves a series of blades which wipe the heat-transfer surface of the dryer. The knives or doctor blades provide some degree of agitation and reduce the fouling on the heat-transfer surface. The material passing through such a dryer must remain fairly fluid. Such devices would not, for instance, be effective in drying sludge solids to a moisture content of 15 percent. The maximum sludge solids content which has been satisfactorily handled in wiped-surface drying equipment is 50 percent. The available heat-transfer surface is relatively small. Such units should be considered only for very wet sludges, where some reduction in moisture (rather than drying to a solid form) is necessary.

Wiped-film evaporators generally have excellent heat transfer coefficients, in the range of 60 to 120 cal/sec sq cm °C (50-100 Btu/hr sq ft °F). Their use at higher moisture levels generally results in a higher transfer coefficient than would be expected from jacketed/hollow-flight dryer. The inability of wiped-surface evaporators to dry sludge to a moisture level much below 50 percent reduces their usefulness in sludge pre-drying for co-incineration.

Jacketed or Steam-Tube Rotary Dryers

An indirectly heated rotary dryer is similar in size and configuration to the direct-fired rotary dryers described previously, but with the shell of the dryer jacketed to permit heating by steam or combustion gases. Steam tubes are often placed inside such dryers to increase the available heat-transfer surface. Industrial applications of such dryers are generally limited to cases where direct fire cannot be used, e.g. drying of solids wetted with flammable solids, drying of materials which are sensitive to carbon dioxide, or drying under vacuum conditions.

Jacketed rotary dryers are best used with free-flowing solids, but could be used for partial drying of sludge. Clearly, a high degree of dry sludge recycle must be provided. Steam-tube rotary dryers, in particular, require very free-flowing solids.

Heat-transfer coefficients for such dryers are relatively low, about 6.2 to 24.8 cal/sec sq cm °C (5-20 Btu/hr sq ft °F), since they are generally used with low-moisture solids. Only a portion of the total available heat-transfer surface is in contact with the solids, thus reducing the overall heat transfer coefficient. This fact, plus the free-flowing solids requirements, severely limits the potential for jacketed or steam-tube rotary dryers in co-incinerator applications.

Other Dryer Types

There are other types of solids-drying equipment which use indirect heat transfer. Most, such as twin-cone or tumble dryers, operate on a batch basis and are therefore unsuited to continuous sludge drying.

Flakers can also be used as dryers, although they are generally used for simple heating and cooling. Flakers resemble rotary vacuum filters in appearance. A large, slowly rotating drum is coated with a layer of solids, slurry, etc. and is steam- or oil-heated from inside. After the material is dried, a knife scrapes the solids from the drum. When drying very wet solids, U_o is in the range of 62 to 99 cal/sec sq cm °C (50-80 Btu/hr sq ft °F), but U_o falls rapidly as the solids approach dryness, because of poor agitation and the use of only conductive heat transfer.

Vibrating-conveyor dryers employ a steam-heated metal plate or tray to dry the solids. The tray is heated from beneath and, as the solids are deposited, the vibrating action provides agitation to prevent formation of a large cake. Such dryers are useful only with free-flowing solids.

Multiple-tray dryers, similar in configuration to multiple-hearth furnaces, have also been used in indirectly heated solids-drying applications. The individual trays and the rabble arms are hollow, for steam heating. Wet solids are charged at the dryer top, and the rabble arms provide some agitation while moving the solids from tray to tray, down the dryer. While heat transfer in such equipment is relatively good, this type of dryer is also limited to free-flowing solids.

Heat and Material Balance

After consideration of the available types of indirect-drying equipment, the jacketed/hollow flight dryer was selected for the technical feasibility study. The heat-and-material balance is based on sludge and refuse quantities and characteristics presented in Appendices C and D; an equivalent-population ratio of sludge to refuse is used. A minimum flue-gas temperature of 760°C (1,400°F) is required for odor destruction.

To establish a heat balance, the Weston co-incineration model was run at three moisture levels representing thickened sludge (4 percent solids), vacuum-filtered sludge (20 percent solids), and pressure-filtered sludge (45 percent solids), with refuse in all cases assumed to contain 28 percent moisture. Table 6 gives the input and output of the INCIN program applied to indirect-dryer co-incineration. These results are summarized on Figure 8.

TABLE 6. INPUT AND OUTPUT OF ANALYSIS OF INDIRECT DRYER CO-INCINERATION ALTERNATIVE BY INCIN PROGRAM -- EQUIVALENT SLUDGE/REFUSE PRODUCTION

Refuse %	Sludge %	Sludge Solids %		Vapor %	Total Moisture %		Furnace Outlet Temp. (°F) Excess Air (%)				
		As Rec'd	As Burned		As Burned	As Chg'd	0	100	200	300	400
35	3	4	85	62	10	72	1,910	1,480	1,220	1,030	900
71	7	20	85	22	21	43	2,750	1,910	1,470	1,200	1,020
84	9	45	85	8	25	32	2,970	2,000	1,520	1,230	1,040

The computer-modeled heat balance indicates that co-incineration is feasible over a broader range of sludge moisture content than is true of direct drying. At 150 percent excess air, a 760°C (1,400°F) temperature can be maintained at an total (sludge and refuse) moisture content of 70 percent, compared with 50 percent for the direct dryer. A 70 percent overall moisture feed corresponds to a sludge moisture of close to 95 percent, i.e. 5 percent sludge solids, if 28 percent moisture is assumed in the refuse. Thus, at an excess air rate of 125 percent, within the normal operating range of a boiler-incinerator, co-incineration of thickened sludge is feasible. However, with a 4%-solids sludge at an equivalent population ratio, there is little margin for the normal fluctuations in sludge and refuse moisture. With a vacuum-filtered sludge of 20 percent solids, excess air rates can approach 225 percent; and with 45 percent solids sludge, excess air can be as high as 250 percent.

Although there is sufficient heat available to dry a thickened sludge, vacuum filtration, at least, is recommended, because drying a 4%-solids sludge would require a vastly larger dryer. The potential for fouling of the heating surface is also greater with a low-solids feed, and a high level of solids recycle would be necessary. Starting with a 4%-solids thickened sludge will

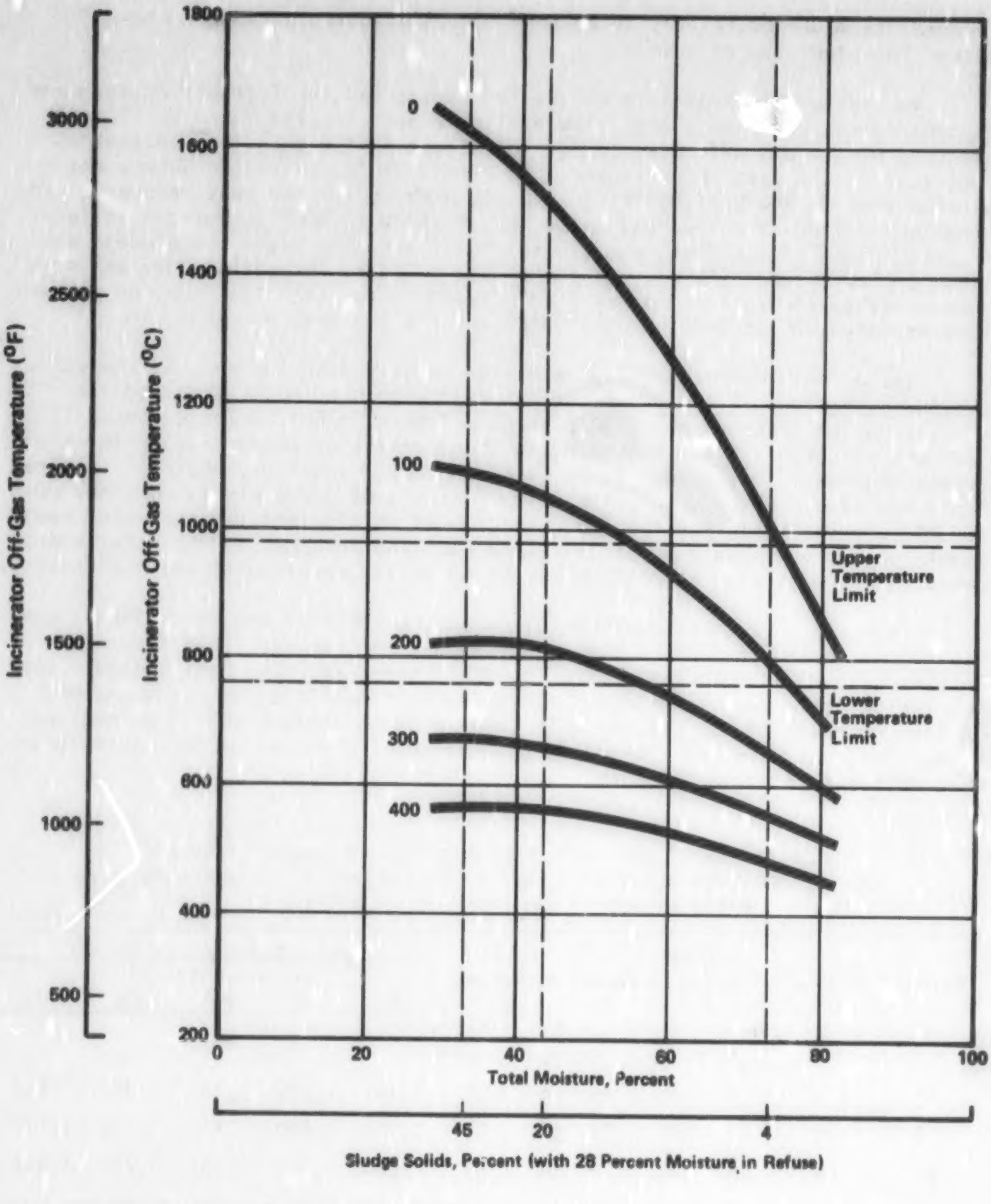


Figure 8. Indirect-Dryer Co-Incineration Gas Temperature (Equivalent Population).

reduce steam demand to only 15 percent of boiler output, thereby providing steam for plant use or sale.

The temperature/moisture curves for direct and for indirect dryers have approximately the same shape. The available heat, as indicated by flue-gas temperature, drops off more rapidly for direct drying than for indirect as moisture in the feed is increased. In direct drying, flue-gas leaves the incinerator at 760°C (1,400°F) (minimum), with no further heat recovery. In indirect drying, the flue-gas is raised to 760°C (1,400°F), but the boiler recovers much of the heat, and flue-gas will actually leave the process at 200° to 260°C (400°-500°F). As the sludge moisture increases, more and more water leaves the incinerator at 760°C (1,400°F) for the direct-drying process, but at only 200° to 260°C (400°-500°F) for the indirect process.

The actual indirect drying operation is very much the same as the direct drying operation. Sludge is first premixed with previously dried solids (entering the dryer at about 50 percent moisture) and is dried to about 15 percent moisture. Steam generated in the incinerator waste heat boiler provides the heat. Dry sludge is conveyed to the incinerator, where it is fired in suspension. Water vapor plus a small amount of purge air is combined with overfire excess entering the incinerator. As an alternative, the water vapor could be condensed in a barometric condenser and returned to the water treatment plant, with only a small volume of purge air returned to the incinerator.

Figure 9 is another representation of the indirect process, with sludge increased to 120 percent of equivalent population ratios. This figure summarizes input and output data from the INCIN program. The data indicate that co-incineration with a 4%-solids sludge remains feasible, but at a maximum excess air rate of 100 percent. The operating conditions for 20 percent excess sludge at 20%- and 45%-solids remains about the same as for equivalent-population ratios.

TABLE 7. INPUT AND OUTPUT OF ANALYSIS OF INDIRECT DRYER CO-INCINERATION ALTERNATIVE BY INCIN PROGRAM -- SLUDGE/REFUSE RATIO AT 120 PERCENT OF EQUIVALENT VALUE

Refuse %	Sludge %	Sludge Solids %		Vapor %	Total Moisture %		Furnace Outlet Temp. (°F)				
							Excess Air (%)				
		As Rec'd	As Burned		As Burned	As Chg'd	0	100	200	300	400
32	2	4	85	65	9	75	1,740	1,380	1,140	980	860
67	8	20	85	25	20	45	2,700	1,890	1,460	1,190	1,010
81	10	45	85	9	24	33	2,960	1,990	1,520	1,230	1,040

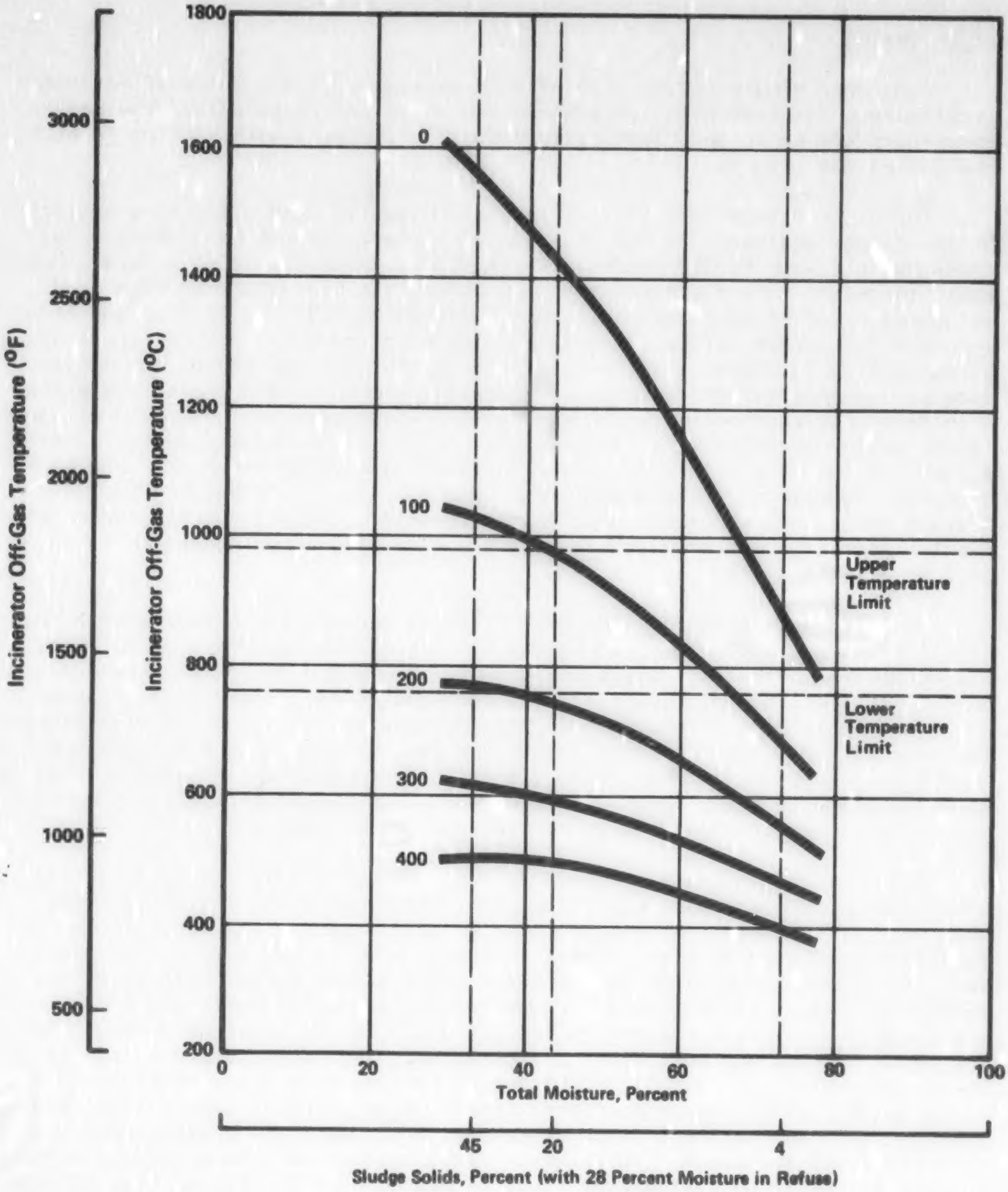


Figure 9. Indirect-Dryer Co-Incineration Gas Temperature (20% excess sludge).

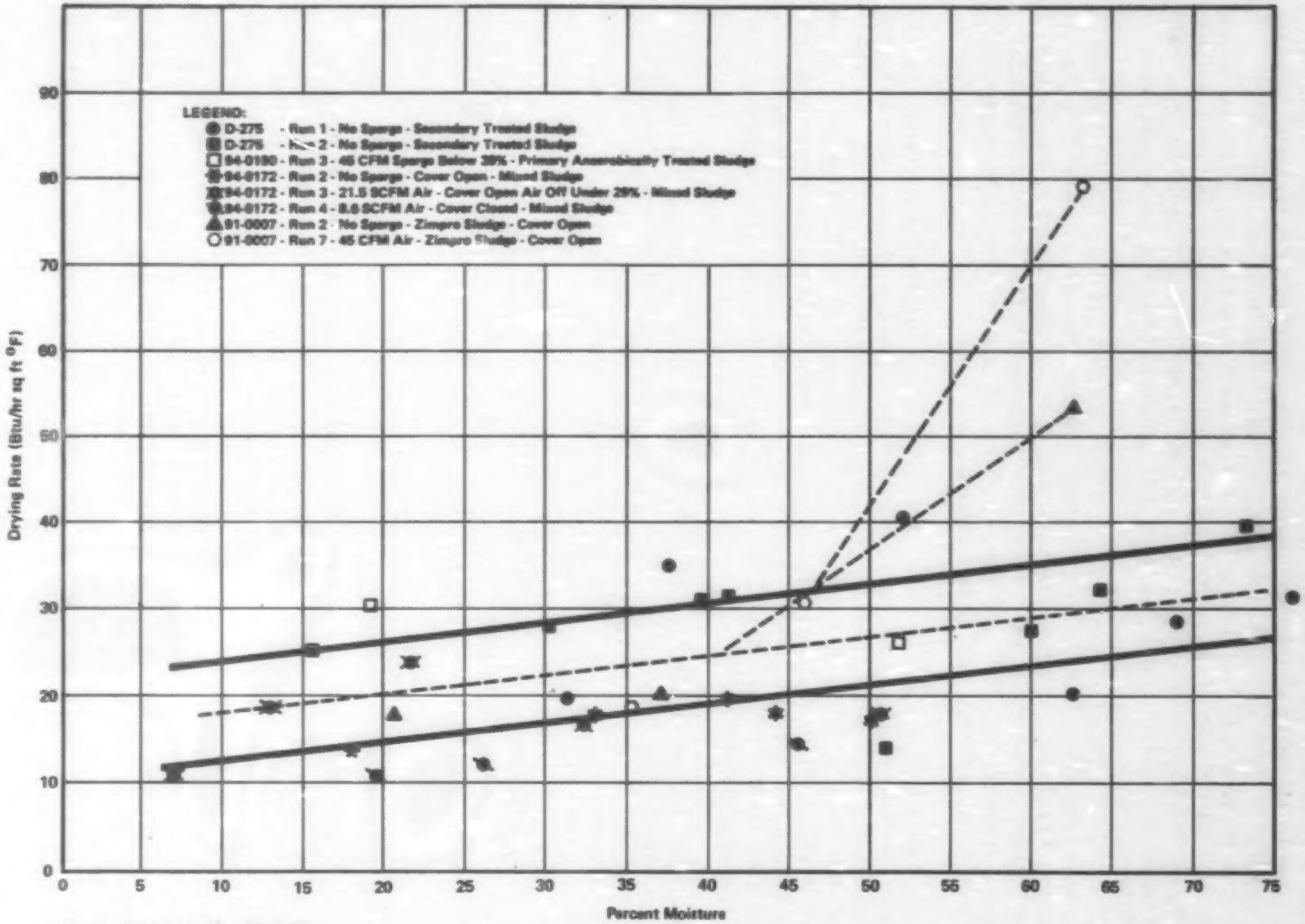
Dryer Design

Some preliminary design data will be necessary to determine if equipment requirements for indirect-drying/co-incineration are reasonable. The design parameters are based on a jacketed/hollow-flight dryer, with heating in both the jacket and flights.

The major design variable applied to indirectly heated jacketed and/or hollow-flight equipment is the heat-transfer coefficient. An average value of 24 cal/sec sq m °C (20 Btu/hour sq ft °F) is typical of such dryers. However, there are many factors which will affect the heat-transfer rate, and values of U_o of 12 to 96 cal/sec sq m °C (10-80 Btu/hour sq ft °F) have been reported for sludge drying. Generally, the heat-transfer rate decreases as sludge solids increase; thus, as sludge moves through the dryer, the drying rate can be expected to decrease. Figure 10 is a plot of a typical relationship between sludge solids and heat-transfer coefficient. The source of the sludge will also affect the sludge drying rate. Higher heat-transfer coefficients are obtained with raw primary and secondary sludge than they are with digested sludges, as indicated in test data supplied by Bethelehem Co. (Figure 10). Fouling of the heat transfer surface can drastically reduce effective heat transfer and is most likely the cause of poor operation in an indirect-drying system.

Recycling dry sludge solids significantly reduces the potential for fouling of the dryer surface. Experience with direct rotary dryers at Holyoke, Massachusetts indicates that sufficient dry sludge should be returned and mixed with incoming wet sludge so that the feed to the dryer contains about 50 percent moisture. Although reducing the feed moisture content also reduces the overall heat-transfer coefficient, the loss is more than offset by the reduction in surface fouling. The effective working volume of such a dryer is about 40 percent of the total volume available in the empty shell. However, all drives should be designed to handle a fully loaded shell.

Rotor speed is generally about 20 rpm. Higher rotational speed increases power consumption and wear on moving parts and reduces the residence time, with very little increase in heat-transfer coefficient. The pitch of the rotor flights or paddles also affects residence time in the dryer. The presence of the rotary joint on the agitator shaft limits steam pressure in the rotor to 11 kg/sq cm (150 psi). Higher pressures can often be accommodated in the jacket; however, excessive wall temperature in the dryer will result in increased fouling and possible char formation. Skin temperature in the dryer should be limited to 180° C (350°F), corresponding to a steam pressure of 9.5 kg/sq cm (135 psi). Where equipment cannot be designed to handle this steam pressure, non-aqueous heat-transfer agents, with lower vapor pressures, can be substituted for steam. To maintain high, uniform wall temperatures throughout the dryer, a condensing-type fluid is preferred. The latent heat of such fluids is 30-50 percent of the latent heat of steam, and the system must be designed to accommodate higher gas and liquid flow rates.



Source: Bethlehem Corp. Test Data

Figure 10. Heat-Transfer Coefficient for Sludge Drying.

Some air flow through the dryer is necessary to purge water vapor. The dryer should be closed or covered, but not vapor-tight. A slight negative pressure should be maintained throughout the dryer to eliminate vapor leakage and the resulting odor problem. Available data also indicate that an air purge or sparge under the solids will substantially improve heat transfer and drying rate. Air flows of 2 to 10 cu m/min per cu m of dryer working volume (2-10 cfm/cu ft) have been effective. An air purge is particularly important as the sludge becomes dry and the heat-transfer coefficient decreases (see Figure 10).

The moisture content of sludge solids leaving the dryer should be about 15 percent. Attaining complete dryness not only is unnecessary, but would also significantly increase the dryer size because of the low heat-transfer coefficient encountered with dry sludge. Dry sludge is also very dusty and would present a potential explosion hazard.

Water vapor and purge air drawn from the dryer should be returned to the incinerator for destruction of odorous materials. Where the design calls for high air-purge rates, a cyclone in the water vapor/air line will reduce the potential for solids build-up in the return duct work. Insulation of the return duct work is also advisable to minimize condensation of water vapor and build-up of solids carried over from the dryer. The water-vapor/purge-air should be combined with overfire air and injected into the active combustion zone of the incinerator.

The dried sludge solids are divided between recycle and solids sent to the incinerator. The recycle solids and the incoming filter cake should be adequately mixed in a pug mill to produce a dryer feed with reasonable moisture distribution and to break up the sludge cake. The remaining dry sludge solids can be conveyed to the incinerator by belt, screw, or pneumatic conveyor. Conveying equipment should be closed and reasonably air-tight, to minimize odor emission. It is generally desirable to spread the sludge throughout the active combustion zone of the incinerator; a pneumatic injector will adequately spread the dry solids and result in suspension burning of the sludge.

Effect of Size on Feasibility

Indirect-contact dryers are available in an almost unlimited range of heat-transfer area, from several square meters to several hundred square meters. Where large capacity is needed, multiple units can be installed. Technical feasibility, therefore, is not affected by dryer size availability.

As with the direct dryer, the sludge predrying section is directly associated with a refuse incinerator. With a small incinerator plant of 230 metric tons (250 tons) per day, co-incineration is feasible for a community of 150,000 or more. In smaller communities where the incinerator is operated less than 24 hours per day, indirect drying offers additional advantages in requiring less start-up time than does a direct-drying process. Intermittent operation does reduce the potential steam sale.

With the small size of indirect-drying equipment and the low proportion of total steam consumption, some reduction in manpower may be achieved by oversizing the dryer and co-incinerating on a one- or two-shift basis.

MULTIPLE-HEARTH CO-INCINERATION

Co-incineration in a multiple hearth furnace has been chosen for detailed study because this technique has been commercially demonstrated in Europe and represents equipment familiar to those in the wastewater sludge disposal field. It is also a technique which does not require a separate sludge dryer, which tends to simplify the co-incineration process. However, this technique requires refuse pre-shredding. A block flow diagram for co-incineration in a multiple-hearth furnace appears in Figure 11.

All commercial multiple-hearth furnaces have essentially the same configuration. The furnace consists of a vertical cylinder, usually lined with refractory, containing a series of horizontal decks or trays (the hearths of the furnace). Hearth openings alternate at the center and outside. A vertical shaft extends through the center of the furnace, with rabble arms extending radially from the shaft at each hearth. These areas provide for agitation and movement of the solids, as the shaft and rabble arms are slowly rotated. In high-temperature operation, the shaft and arms are hollow, for the passage of cooling air.

Combustion air enters at the base of the furnace. Where high-moisture-content sludges are dried, warm exhaust air from the center-shaft cooling system is often used as part of the combustion air supply. Combustion air and flue-gases move counter-current to the sludge flow. For sludge incinerators, normal excess air level ranges from 50 to 100 percent.

In sewage sludge incineration, the wet sludge is charged at the top hearth. By the action of the rabble arms, the sludge moves across the hearths until it reaches the drop holes, where it falls to the next hearth. Rising combustion products provide the heat to dry the sludge as it moves across the top two or three hearths. Once the sludge is dry, combustion starts. Burners are generally installed to provide ignition of the dry sludge and make-up heat for sludge drying. Combustion continues on the next few hearths. After burnout, the furnace design generally includes one additional hearth, for ash cooling and for some combustion air preheating. Ash is discharged at the base of the furnace. Thus there are three zones in a typical sludge incinerator: drying, combustion, and cooling. Typical operating temperatures and conditions for a six-hearth furnace are as in the next tabulation. In larger furnaces , the same three zones are present, but are spread over more hearths.

Typical multiple-hearth sludge incinerators range from 1.8 to 8.5 m (6 - 28 ft) in diameter and have from 4 to 12 hearths. In addition to their use in sludge disposal applications, multiple-hearth furnaces are used for ore roasting and reduction, calcining, and char production.

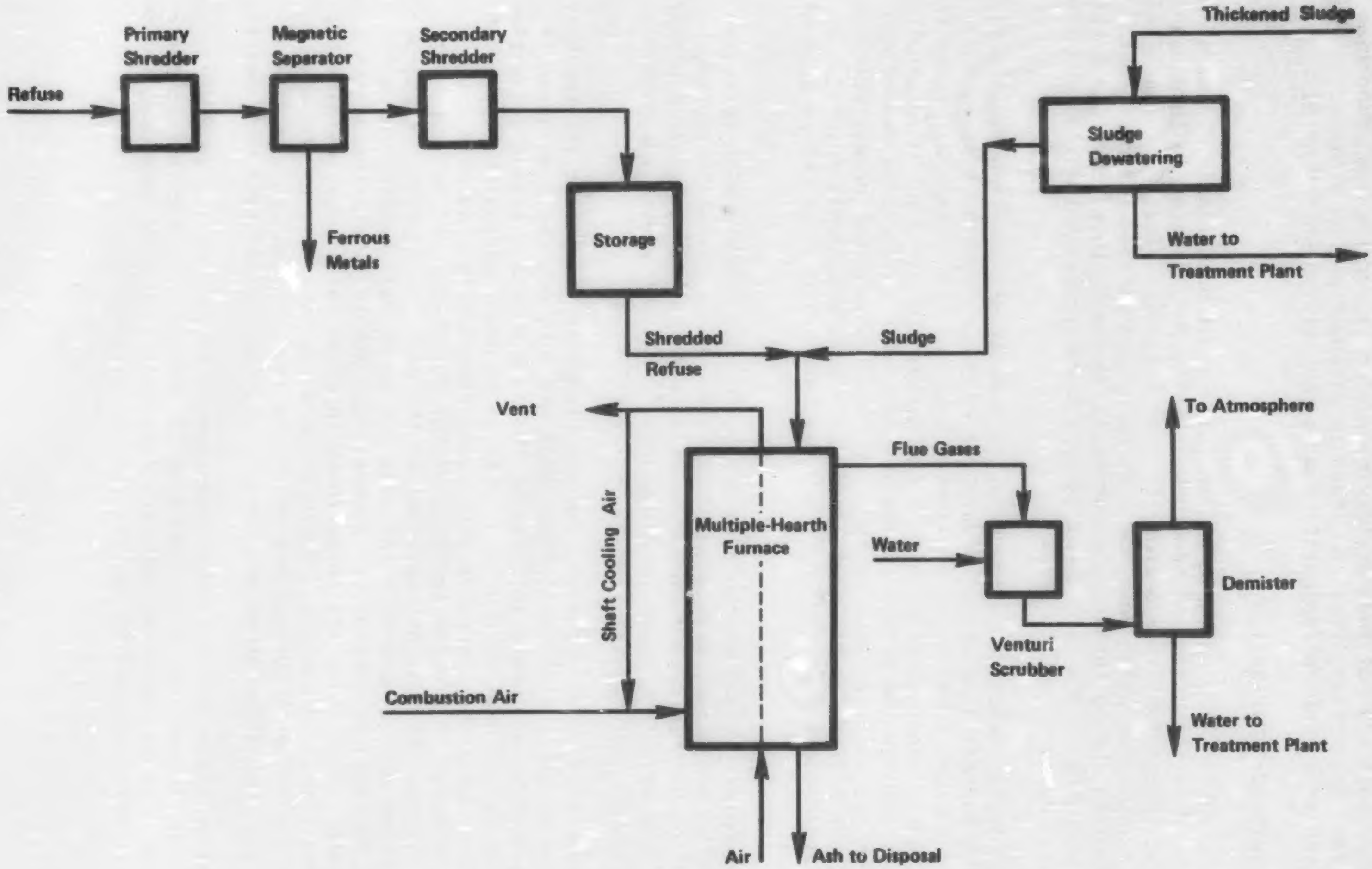

Refuse
Primary Shredder
Magnetic Separator
Ferrous Metals
Secondary Shredder
Storage
Shredded Refuse
Thickened Sludge
Sludge Dewatering
Water to Treatment Plant
Sludge
Vent
Shaft Cooling Air
Combustion Air
Multiple-Hearth Furnace
Air
Ash to Disposal
Flue Gases
Water
Venturi Scrubber
Demister
To Atmosphere
Water to Treatment Plant

Figure 11. Multiple-Hearth Co-Incineration: Schematic Flow Sheet.

Hearth No.	Gas Temperature (°C)	Gas Temperature (°F)	Sludge Temperature (°C)	Sludge Temperature (°F)	Condition
1	426	799	38	100	Drying
2	538	1,000	66	150	Drying
3	635	1,175	82	180	Drying
4	732	1,350	-	-	Flame
5	913	1,675	-	-	Flame
6	-	-	-	-	Cooling

Heat and Material Balance

For heat-balance purposes, the multiple-hearth incinerator can be considered as a direct-drying process, with all the combustion products passing over the wet sludge, but without recirculating of furnace off-gas back to the combustion zone. It is therefore necessary to maintain a gas temperature of 760°C (1,400°F) after the sludge drying zone in order to insure destruction of odorous materials.

Equivalent population quantities of refuse and sludge were again used as the input to the co-incineration computer model. The model was run with a 4%-solids sludge, representing thickened sludge; a 20%-solids sludge, representing vacuum-filtered suldge; and 45%-solids sludge, representing sludge dewatered by pressure filtration. Table 8 gives the input and output of the program, Figure 12 shows the results graphically.

TABLE 8. INPUT AND OUTPUT OF ANALYSIS OF MULTIPLE HEARTH CO-INCINERATION ALTERNATIVE BY INCIN PROGRAM -- EQUIVALENT SLUDGE/REFUSE PRODUCTION

Refuse %	Sludge %	Sludge Solids %	Total Moisture %	Furnace Outlet Temp. (°F) Excess Air (%) 0	100	200	300	400
35	65	4	72	1,010	780	640	540	470
71	29	20	43	2,520	1,750	1,350	1,100	930
84	16	45	32	2,900	1,950	1,480	1,200	1,020

As the typical operating excess air rate of 100 percent, co-incineration is feasible with overall moisture contents of 57 percent or less. An overall

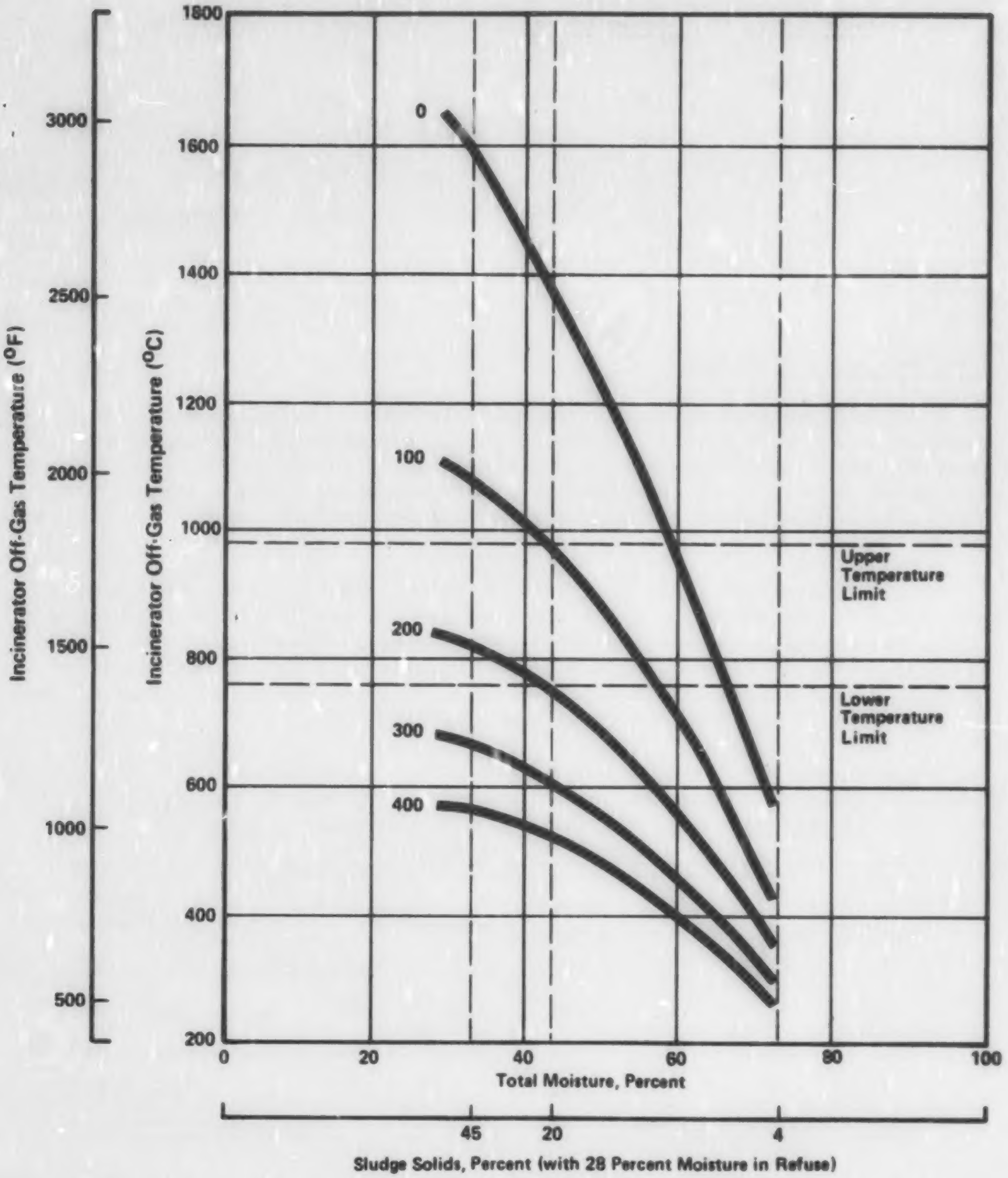


Figure 12. Multiple-Hearth Co-Incineration Gas Temperature (Equivalent Population)

moisture of 57 percent corresponds to a sludge consistency of 8.7 percent solids, which is not a typical solids content available from standard processing equipment. Consequently, solids would have to be dewatered to 20 percent by the use of vacuum filtration or centrifugation. With a feed consisting of 20%-solids sludge and refuse (equivalent-population basis), excess air levels could range as high as 175 percent without adverse effect on the required exhaust temperature. For co-incineration applications, excess air levels of 100 percent have been recommended by vendors.

Co-incineration with 4%-solids sludge does not meet the prescribed temperature requirements and should be considered unfeasible. Sludges with solids higher than 20 percent will, of course, meet the 760° (1,400°F) minimum temperatures at all reasonable excess air rates for multiple-hearth incinerators.

Figure 13 is based on incineration model results (Table 9) with sludge at 20 percent above the equivalent-population basis. This reduces the overall moisture limit to 54 percent, which corresponds to a sludge solids level of 10 percent. However, none of the sludge treatment techniques generally used produces a sludge near 10 percent solids. Thickened sludge at 4 percent and vacuum filtered sludge at about 20 percent solids are the sludge treatments producing solids closest to the 10 percent required. Since the 4%-solids sludge does not meet the temperature requirements a 20%-solids, vacuum-filtered sludge represents the minimum sludge solids level which can be co-incinerated without the use of significant quantities of auxiliary fuel.

TABLE 9. INPUT AND OUTPUT OF ANALYSIS OF MULTIPLE HEARTH CO-INCINERATION ALTERNATIVE BY INCIN PROGRAM -- SLUDGE/REFUSE RATIO AT 120 PERCENT OF EQUIVALENT VALUE

Refuse %	Sludge %	Sludge Solids %	Total Moisture %	Furnace Outlet Temp. (°F) Excess Air (%) 0	100	200	300	400
67	33	20	45	2,440	1,700	1,310	1,070	910
81	19	45	32	2,870	1,940	1,470	1,200	1,010

From the standpoint of the available heat, a multiple-hearth furnace acts the same as the direct pre-drying process, but operates at lower excess air levels than refractory incinerators.

Plant Design

The actual design work for a multiple-hearth incinerator is normally provided by the equipment vendors. However, there are some basic parameters which should be kept in mind when considering a multiple-hearth co-incineration plant; the most significant parameter is hearth loading. Several factors affect the loading rate: moisture content, volatiles content, and size and

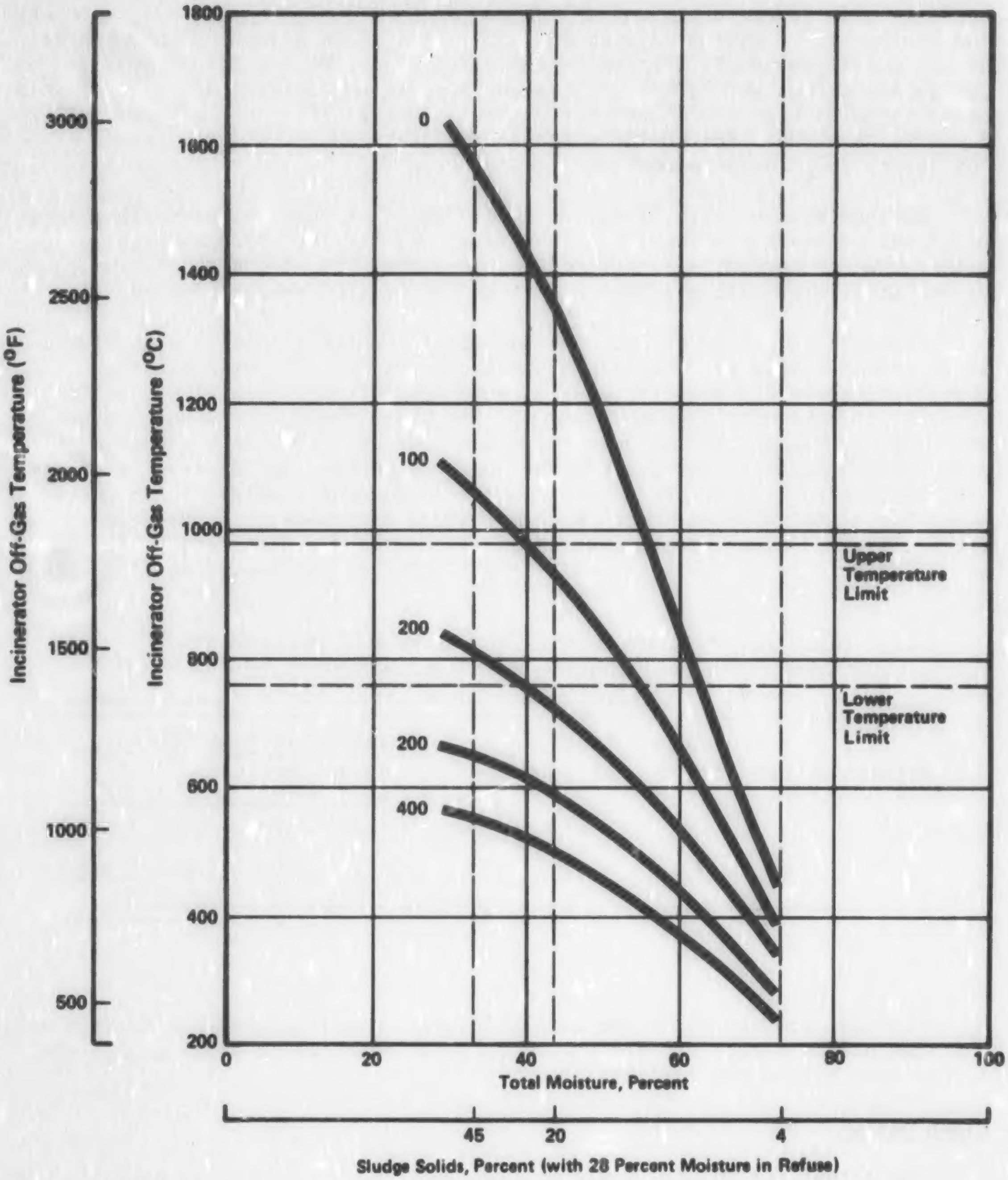


Figure 13. Multiple-Hearth Co-Incineration Gas Temperature (20% excess sludge)

consistency of feed materials. Design loading must be adjusted to provide sufficient drying time in the drying zone and reasonable heat release in the active combustion zone of the furnace. For burning sludge alone, typical hearth loading ranges from 34 to 59 kg of wet sludge per hour per sq m (7-12 lb/hr per sq ft) of hearth area. The loading should be reduced, to 29 to 49 kg/hr per sq m (6-10 lbs/hour/sq ft), when co-incinerating sludge and refuse, because of the high heat release of the refuse. Small-diameter furnaces operate at the lower end of the range, while higher loadings can be expected with large-diameter units.

Where significant quantities of water are present, it is often useful to consider loading on a solids basis. On this basis, there is little difference in loading between simple sludge incineration and co-incineration. Expected solids loading will be in the range of 15 to 24 kg/hr solids per sq m (3-5 lb/hr/sq ft).

On occasion, the combustion spaces over the uppermost one or two hearths of a furnace are used to insure the burn-out of odors in the off-gases; with auxiliary-fuel firing, these spaces can be used as afterburners, to raise off-gas temperature. In such cases, the area of the inactive hearths should not be included when considering hearth loading.

In general, the largest (diameter) furnace consistent with the foregoing hearth loadings should be provided in the plant design. Large-diameter furnaces have a larger drop-hole opening and more total open area than do the smaller-diameter hearths. Larger openings will reduce the potential for drop-hole plugging attributable to oversized refuse or clinkers. In no case, however, have furnaces with less than six hearths been successful in co-incineration applications; this is the minimum number of hearths necessary for adequate burn-out of the refuse/sludge.

Two methods of feeding sludge and refuse to a multiple-hearth furnace have been tested: combined feed to the top hearth and sludge feed to the top hearth with refuse feed to a lower hearth. Both feed systems have been used successfully, but the systems with sludge feed to the top hearth and refuse feed to a lower hearth have experienced odor-emission problems if off-gas temperatures are not kept above 760°C (1,400°F). With combined top feed, it may be necessary to provide some premixing of shredded refuse with the sludge before charging the furnace; reports from the Uzwil (Switzerland) installation indicate that combustion of refuse occurs in the top hearth if the refuse and sludge are not mixed. High carbon monoxide concentrations in the off-gas have also been detected at the Uzwil unit. Separate feed is a more complex system, but offers greater flexibility and control of sludge-to-refuse ratio and may also produce more efficient sludge drying. It is therefore the recommended arrangement for co-incineration feed to a multiple-hearth furnace.

Multiple-hearth co-incineration requires the refuse to be shredded and cleaned of metal before entering the incinerator, to minimize entanglement problems with the rabble arms and plows. Shredded refuse must be small enough to fall through the drop-holes in each hearth of the furnace, but there has been insufficient experience to determine the precise extent of refuse shredding required. Based on European practice, a refuse maximum size of

7.6 cm (3 in.), i.e., 95 percent passes this size of mesh, is recommended by equipment vendors for furnaces with diameter of 3 m (10 ft) or more.

Shredding to this size is best accomplished in two stages. First, bulky waste should be separated. Refuse is then rough-shredded to permit magnetic separation of ferrous metals. At this point, the refuse can be screened to reduce large, non-combustible pieces by the removal of glass, non-ferrous metals, etc. The refuse is then fine-shredded to a 6.7 cm (3 in.) max. size. A certain amount of pieces of refuse as large as 15 cm (6 in.) can be accommodated in the furnace, but the fraction in the 7.6 to 15 cm (3 in.-6 in.) range must be small. Significant quantities of material over 7.6 cm (3 in.) will result in poor rabbling on the hearth and blockage of the drop-holes. Wire and similar material must also be removed before the refuse is fed to the furnace, because they may interfere with furnace operation by wrapping around tines on the rabble arms and on the center shaft of the furnace.

Refuse shredding is a high-maintenance operation with relatively restricted equipment availability. To maintain incinerator operation during shredder down-time, facilities for storage of shredded refuse equivalent to at least two days' capacity should be provided. Special care is required in the design of shredded refuse storage silos to avoid severe compaction and bridging.

The requirement for shredded refuse and storage will add significantly to the cost and complexity of a multiple-hearth co-incineration plant. One European plant has avoided the shredded refuse problem by a modification in the plant design. At Dordrecht, Holland, refuse is incinerated in a conventional refractory incinerator equipped with Martin grates; no refuse shredding is required. Combustion products are ducted to the normal combustion air inlet of a multiple-hearth incinerator. At this point, there is sufficient oxygen for combustion of the sludge, because of the high excess air levels used in the refuse incinerator. Sludge is fed at the top of the multiple-hearth furnace, where it is dried, and it is incinerated in the lower section of the multiple-hearth furnace. By this process, heat from refuse incineration, in the form of preheated combustion air, is used in sludge drying and incineration. While two separate furnaces are required in this design, the process is simplified by elimination of the shredding operation and its related problems. The plant continues to operate with no auxiliary fuel required in the sludge incinerator. A diagram for this alternative multiple hearth co-incineration process appears in Figure 14.

Effect of Size on Feasibility

Multiple-hearth incinerators are available in wide range of sizes, from 0.3 to 9 m (1' - 30') in diameter and from 2 to 12 hearths. As furnace diameter decreases, drop-hole size also decreases, which in turn increases the amount of refuse shredding necessary. The ability to shred refuse becomes the limiting factor in scale-down of a multiple hearth co-incineration unit.

A refuse of 2.5 cm (1 in.) nominal size can be incinerated in a 2.7 m (9 ft) diameter, 2 m (7 ft) I.D. furnace. With six hearths, this furnace would have an effective area of 19 sq m (200 sq ft), and could handle about

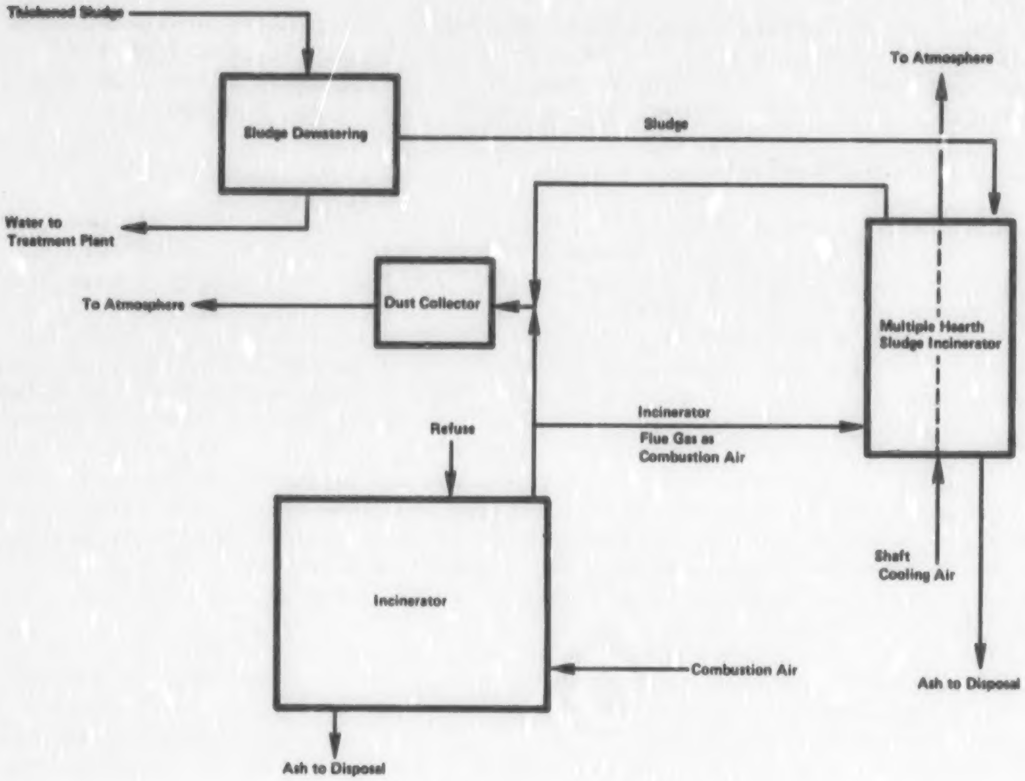

Thickened Sludge
Sludge Dewatering
Water to Treatment Plant
To Atmosphere
Sludge
Dust Collector
To Atmosphere
Multiple Hearth Sludge Incinerator
Refuse
Incinerator Flue Gas as Combustion Air
Incinerator
Shaft Cooling Air
Combustion Air
Ash to Disposal
Ash to Disposal

Figure 14. **Multiple-Hearth Co-Incineration Using Incinerator Flue Gas—Schematic Flow Sheet**

14 metric tons (15 tons) per day (24-hr operation) of refuse and sludge. Since the required refuse size is small and it is impractical to install a shredder whose capacity is less than 1.8 metric tons (2 tons) per hour (because of the small size of the feed chute and shredder opening relative to typical raw refuse dimensions), the shredding sub-system in such an installation would account for a higher proportion of the overall cost than it would with a larger co-incineration furnace.

The smallest shredder generally used with municipal refuse has a capacity of about 18 metric tons (20 tons) per hour, which would permit a co-incineration plant to handle 110 metric tons (120 tons) per day of refuse when operating 6 hours per day. This refuse rate is equivalent to a co-incineration plant of about 172 metric tons (190 tons) per day (of refuse and sludge) and would serve a community of about 100,000. Furnace diameter for this capacity would be 4.9 to 5.5 m (16 - 18 ft).

The largest furnace commercially available will provide up to 510 sq m (5,500 sq ft) of hearth with a rating of about 450 metric tons (500 tons) per day of combined feed. A single furnace in this size would serve a population of 250,000. Beyond this point, multiple units would be required.

PYROLYSIS CO-INCINERATION

The use of pyrolysis for processing mixed municipal refuse has been advocated primarily as a means of recovering some of the fuel value in refuse. Until recently, attempts at energy recovery from refuse combustion have been based on the generation of steam in a boiler-incinerator. The problems associated with steam generation have been logistics (use must be near the incineration), low boiler pressure (not efficient for power generation), and intermittent operation. Thus, pyrolysis of mixed municipal refuse has a two-fold objective: 1) incineration of refuse, with all the related advantages; and 2) production of energy in the form of a fuel product. The same factors which improve energy recovery should prove useful in co-incinerating sludge and refuse. Studies thus far have indicated that low excess air rates are required for co-incineration, primarly to conserve available heat. Pyrolysis, with its sub-stoichiometric air/oxygen usage should provide a high level of heat availability. A block flow diagram for co-incineration appears as Figure 15.

In concept, pyrolysis of an organic substance is a destructive distillation process wherein the solids are heated in a partial or total absence of oxygen. The solid decomposes, producing a gaseous product and carbonaceous residue called "char." The gaseous products are often partially condensed, forming a liquid product as well.

The gaseous products consist of typical combustion products, carbon dioxide, and water vapor, even though little actual combustion may have occurred in the pyrolysis equipment. These oxidized compounds are present in combined form in many organic substances, or are formed from oxygen available in the solids undergoing pyrolysis. The fuel value of the pyrolytic gas is derived from the presence of carbon monoxide, hydrogen, methane, and other light hydrocarbons.

If the gaseous products of pyrolysis are cooled, a liquid product will condense. The bulk of the liquid product is water, but significant quantities of organics also condense. These include methanol and higher alcohols, benzene and other aromatics, and, to a lesser extent, aldehydes, ketones, and organic acids.

The residue which remains after pyrolysis contains the ash or non-combustibles of the original material, plus a carbon char. The char component of the residue also has a fuel value, similar to that of bituminous coal. In certain pyrolysis processes, this char is combusted within the furnace (slagging furnaces) to provide the heat necessary to carry on the reaction. This is an appropriate use of the char component, because the carbon portion is difficult to separate from ash, and its external use as a fuel is doubtful.

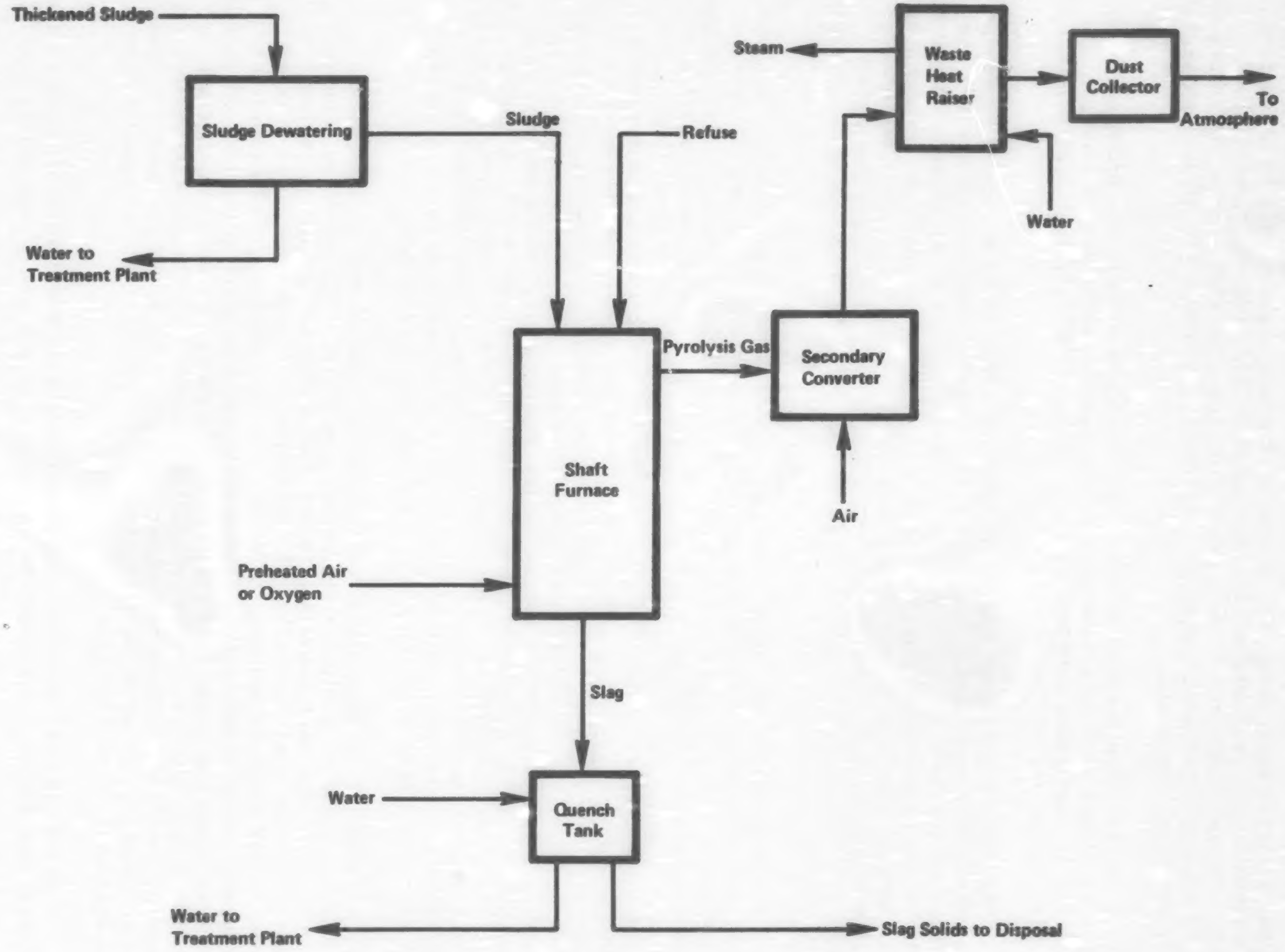

Thickened Sludge
Sludge Dewatering
Water to Treatment Plant
Sludge
Refuse
Steam
Waste Heat Raiser
Dust Collector
To Atmosphere
Water
Pyrolysis Gas
Secondary Converter
Shaft Furnace
Air
Preheated Air or Oxygen
Slag
Water
Quench Tank
Water to Treatment Plant
Slag Solids to Disposal

Figure 15. Pyrolysis Co-Incineration — Schematic Flow Sheet.

Pyrolysis for the production of organic chemicals has been, and continues to be, a significant industrial process. Early processes for the production of methanol were derived from the destructive distillation (pyrolysis) of wood. Thermal cracking of heavy petroleum stocks to form lighter hydrocarbons could also be considered a pyrolytic operation, as could the production of fuel oils and gases from coal.

A variety of pyrolytic equipment is available or has been proposed. One means of classifying this equipment is the way in which heat to carry on the reaction is supplied: indirect heating, direct auxiliary fuel firing, and partial combustion of the refuse.

The pyrolysis reactor can be heated externally as in a retort. This is the most widely used form of pyrolysis in industrial applications, where the purpose of the reaction generally is the production of a new organic chemical. Much of the experimental work on the pyrolysis of mixed municipal refuse has also been carried out in such vessels, utilizing externally supplied heat to initiate and maintain reaction temperature. However, it is unlikely that commercial-scale co-incineration equipment could be operated using an indirect heat source.

A second system employs an auxiliary fuel, fired directly into the pyrolysis chamber, to provide the energy input to maintain the pyrolysis reaction temperature. Such a system, employing a rotary kiln, is the basis for Monsanto's Landgard system. Shredded refuse is ram-fed into the kiln, where auxiliary fuel is fired to maintain an off-gas temperature of 650° (1,200°F) and a residue temperature of 820°C (1,500°F). The pyrolytic gases and refuse move through the kiln countercurrently. The gases are removed and burned in a "gas purifier." Steam is recovered from the combustion products, for sale to a nearby utility; the quantity of steam generated, however, is greater than could be obtained by firing the auxiliary fuel directly into a boiler--thus, the economy of operation. There is no attempt to recover a liquid product, and, since the gas purifier immediately follows the pyrolysis kiln, there is little loss in sensible heat of the pyrolytic gases. Char product does represent a significant loss of potential fuel value; in this installation, the char is removed from the kiln, quenched, and landfilled.

Although it is feasible to co-incinerate in equipment similar to the Landgard process, significant increases in auxiliary fuel would be required; virtually all the heat necessary to dry the sludge would have to be input in the form of residual fuel oil. (A 20%-solids sludge would require a heat input of 789 cal/g (1,421 Btu/lb) of wet sludge.) Although this represents an improvement over simple sludge incineration because small quantities of excess air are fired, the added fuel cost would make co-incineration in this type of equipment unattractive. In addition, the economics of the Landgard system are based on the sale of steam to recover the cost of fuel. While such a system may be feasible, it would be fortuitous to find a major steam customer near the wastewater treatment plant.

A third type of pyrolysis process employs a refractory-lined shaft furnace to carry out the reaction. Refuse is charged at the top of the shaft, providing a seal, and as it descends through the furnace, hot pyrolytic gases from the slagging and combustion zones move in a counter-current direction, thus providing pre-ignition and drying of the sludge and refuse. Pre-heated air or oxygen-enriched air is injected into the combustion zone at the base of the shaft furnace, where combustion of the unpyrolyzed char occurs.

Preheating and oxygen enrichment serve essentially the same purpose: maintaining a furnace temperature high enough to form a slag and to produce a pyrolysis gas with as high a heating value as possible. The intentional formation of a fluid slag, at temperatures of 1,370° - 1,650°C (2,500-3,000°F), is a departure from typical refuse incineration, where slag formation is avoided wherever possible. The slag formed is virtually free of combustibles, and therefore represents the beneficial use of the char portion of typical pyrolysis products, in that the char supplies heat to the pyrolysis reactor while producing a sterile, non-leaching, minimum-heat-value residue.

As the cooled pyrolysis products leave the reactor, two options are available. These gases (low heating value), after preliminary cleaning, can be directed to a remote facility; or they can be burned in a secondary combustion chamber immediately following the shaft furnace, with energy recovery in the form of a waste-heat boiler. Since the primary objective of co-incineration is the combined disposal of sludge and refuse (not energy recovery) and since heating values are expected to be lower with co-incineration than with the pyrolysis of refuse alone, immediate combustion followed by energy recovery, if economically attractive, should be the type of pyrolysis process best suited to co-incineration. In explanation of the expectation of lower heating values for co-incineration pyrolysis, more heat must be provided in sludge addition than with refuse alone in order to evaporate the additional water in the sludge. The only source of this heat is increased combustion of burnable material. Increased combustion will result in higher CO_2 in the gas plus additional moisture in vapor form, thus reducing both the heat content and heating value of off-gases. A full-scale co-incineration experiment is under way in a Purox (Union Carbide) system. There is some indication that the Purox system is affected less by the moisture content than the Torrax system described in the report. Data available from Torrax (Carborundum) indicates a reduction of about 25 percent in total heat available from pyrolysis gases during co-incineration at equivalent population rates of sludge and refuse, with sludge dewatered to 20 percent solids. The major disadvantage of indirect combustion is the expense related to the boiler and to off-gas cleaning equipment.

The major shaft furnace systems available, the Purox (oxygen enrichment) and Torrax (regenerative heat recovery) pyrolysis units, marketed by Union Carbide Co. and The Carborundum Co., have similar basic operating principles. The Purox plant maintains a high slag-zone temperature by oxygen enrichment, and the Torrax process maintains the furnace temperature by recovery of waste heat and combustion air pre-heating in a system of regenerative towers. The oxygen enrichment system is designed primarily for the production of high-Btu fuel gas; thus, the added capital and operating cost of oxygen-generating equipment may be justified. However, where the objective is the use of waste energy in refuse to co-incinerate the sludge by a pyrolysis technique, the use of oxygen enrichment appears to offer little advantage over air preheating if the co-incineration plant is adjacent to the wastewater treatment plant. If an energy consumer can be located nearby, the potential sale of fuel gas or steam should not be ignored, and the equipment type should be re-evaluated in that light.

Heat and Material Balance

With incineration, combustion is assumed to be complete, with well-defined reactions, end products, and heats of reaction. In pyrolysis, with a uniform feed of known composition, the kinetics of reaction can be determined, and the relationship between operating parameters and pyrolytic products can be established. Such information has been developed for a variety of materials, including wood, petroleum products, coal, and even various constituents of municipal refuse, such as cellulose and polyethylene. However, the wide variation in refuse composition makes it impossible to define, exactly, the quality of pyrolytic products generated in the co-incineration reaction period.

One of the major factors affecting the yield of pyrolysis products is the operating temperature of the furnace. The pyrolysis reaction does not occur at any significant rate until the temperature reaches 480°C (900°F). Higher temperature increases the yield and heating value of the pyrolysis gases, and decreases the quantity of char. A reaction temperature of about 820°C (1,500°F) appears to be the minimum operating temperature for reasonable reaction rates and char burn-out.

Slagging-type pyrolysis furnaces, operating at temperatures of 1,370° to 1,650°C (2,500°-3,000°F), produce a slag with virtually no heating value at all. Therefore, maintaining a slagging temperature in the hearth area is a necessary requirement for pyrolysis in a shaft furnace.

Torrax System--

In the system analyzed in the computer model (Torrax), there are two heat sources: 1) partial combustion in the shaft furnace, and 2) secondary combustion of the pyrolysis products. Control of the slagging and pyrolysis temperatures is maintained by controlling the temperature and volume of preheated combustion air injected into the base of the shaft furnace. Secondary combustion of pyrolysis products, outside the shaft furnace, is the source of preheat (through regenerative heat exchangers) for incoming combustion air. (In the Purox system, heat is provided only by the partial combustion of the refuse in the slagging section of the furnace.)

The heat necessary to dry the sludge must be obtained from one or both of these two sources. The secondary combustion occurs outside the shaft furnace, however, and the only way that heat generated in the secondary combustion chamber can be used to evaporate sludge moisture is by pre-heating combustion air through heat exchange in the regenerators. The volume and the temperature of preheated combustion air are limited by the degree of combustion required in the shaft furnace and by the temperature and size limitations of the regenerators; therefore, secondary combustion of pyrolysis products is a poor source of heat for drying the sludge.

The only remaining feasible source of heat, therefore, is the increased combustion of the refuse within the furnace. Increases in the degree of combustion can be closely controlled by increases in the amount of combustion air injected into the base of the shaft. Increasing combustion will provide additional heat to dry the sludge. The pyrolysis gases drawn from the top of the shaft will be lower in fuel value and larger in volume than the gas obtained with refuse alone. The lower fuel value results from additional combustion in the furnace, and the larger volume is attributable to the water vapor evaporated from the sludge. The wet, low-Btu gas is then burned in the secondary combustion chamber, and the combustion products are passed through the regenerative tower (or through a waste-heat boiler) and out to pollution control equipment.

The limits on the feasibility of co-incineration can be expressed in terms of the temperature of the gases exiting from the combustion chamber. As noted in the preamble to this section, a temperature of 760°C (1,400°F) would normally be considered sufficient to insure complete combustion and destruction of odorous gases. Because the combustion products must also supply heat to the regenerative towers, and the temperature of air pre-heated in these towers must be raised to about 1,040°C (1,900°F), which requires a combustion gas temperature of at least 1,150°C (2,100°F). Thus, the temperature of combustion products leaving the secondary combustion chamber becomes the limiting factor in determining the feasibility of co-incineration by pyrolysis.

Figure 16 represents the relationships between combustion gas temperature and the overall moisture and the sludge moisture content (at equivalent-population sludge-to-refuse ratio). The combustion calculations were made by the INCIN model using input described in Table 10.

TABLE 10. INPUT AND OUTPUT OF ANALYSIS OF PYROLYSIS CO-INCINERATION ALTERNATIVE BY INCIN PROGRAM -- EQUIVALENT SLUDGE/REFUSE PRODUCTION

Refuse %	Sludge %	Sludge Solids %	Total Moisture %	Furnace Outlet Temp. (°F) Excess Air (%) 0	10	20	30	40	50
35	65	4	72	1,200	1,160	1,130	1,100	1,070	1,040
71	29	20	43	2,650	2,530	2,420	2,330	2,240	2,160
84	16	45	32	3,000	2,850	2,730	2,610	2,500	2,400

The calculations were performed with 20 percent of the total air requirement pre-heated to 1,040°C (1,900°F), representing the preheated air entering the slagging zone of the furnace. As noted, an overall moisture content of 55 percent (corresponding to sludge solids of 13.5 percent) or less resulted in acceptable operating conditions, that is, secondary combustion chamber

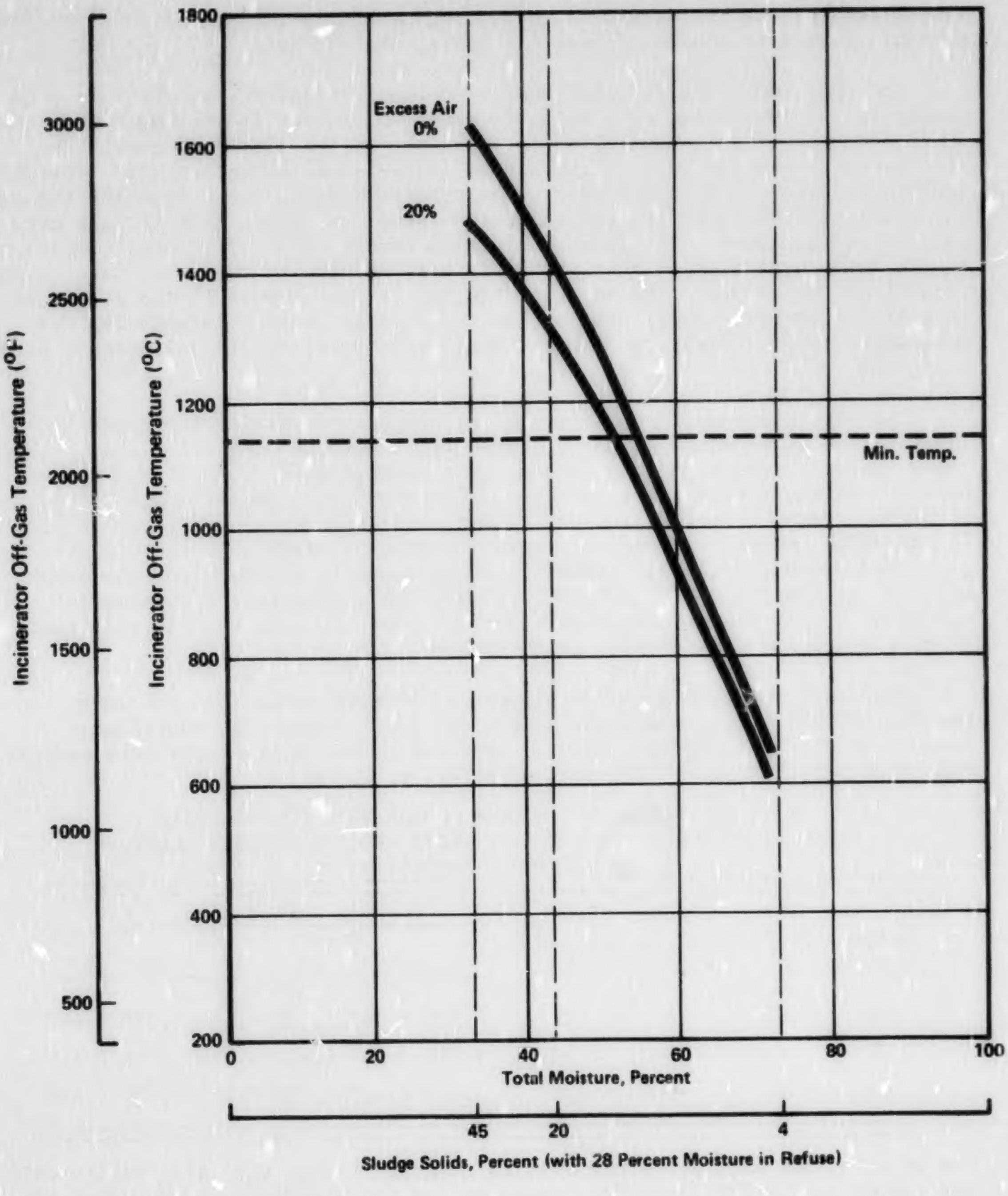


Figure 16. Pyrolysis (Equivalent Population).

off-gas temperatures of at least 1,150°C (2,100°F). Thus, non-dewatered sludge, at 4 percent solids, cannot be co-incinerated with refuse on an equivalent-population basis. Vacuum-filtered sludge at 20 percent solids or pressure-filtered sludge at 45 percent solids results in acceptable performance. Increasing sludge quantities by 20 percent, as suggested for design purposes, also results in satisfactory operating conditions for sludges of 20 percent solids or higher, as indicated in Figure 17, which is based on data presented in Table 11.

TABLE 11. INPUT AND OUTPUT OF ANALYSIS OF PYROLYSIS CO-INCINERATION ALTERNATIVE BY INCIN PROGRAM--SLUDGE/REFUSE RATIO AT 120 PERCENT OF EQUIVALENT VALUE

Refuse %	Sludge %	Sludge Solids %	Total Moisture %	Furnace Outlet Temp. (°F) Excess Air (%) 0	10	20	30	40	50
67	33	20	45	2,570	2,460	2,360	2,270	2,180	2,100
81	19	45	33	2,970	2,830	2,710	2,590	2,480	2,390

Purox System--

Analysis of the Purox system is more complex than that of the Torrax system. Since the only source of heat is partial combustion of the refuse, the temperature/moisture relationship will approach that of a direct-dryer process operated at stoichiometric air levels. (Note that this should lead to a conservative estimate of co-incineration feasibility, since the Purox furnace is actually operated at sub-stoichiometric oxygen levels and no diluent nitrogen is present.) If the pyrolytic gas is immediately combusted, the temperature requirement remains at 760°C (1,400°F) to insure complete destruction of organics. As indicated in Figure 16, co-incineration appears feasible at total moisture contents of 65 percent or less.

Design

All currently available pyrolysis furnaces are based on proprietary designs. Both the Torrax system and the Purox system utilize a shaft furnace. Refuse and sludge are charged at the top and travel down the furnace. As the dry refuse approaches the base of the furnace, air or oxygen is injected and partial combustion occurs. Rising combustion products provide the heat for pyrolysis of the refuse/sludge. The slag is continuously tapped from the furnace and quenched in water, producing an inert solid. The pyrolytic gases are burned immediately, or are cooled to reduce the dew point, and then are sent to a remote combustion unit.

The major problem encountered thus far has been maintaining proper slagging conditions at the base of the furnace, where slag freezing and accumulation result when the bed cools. The principal remedial action is to use auxiliary fuel to maintain proper temperature in the slag-tap area. Occasionally, residue contamination from unburned refuse has been a problem, because

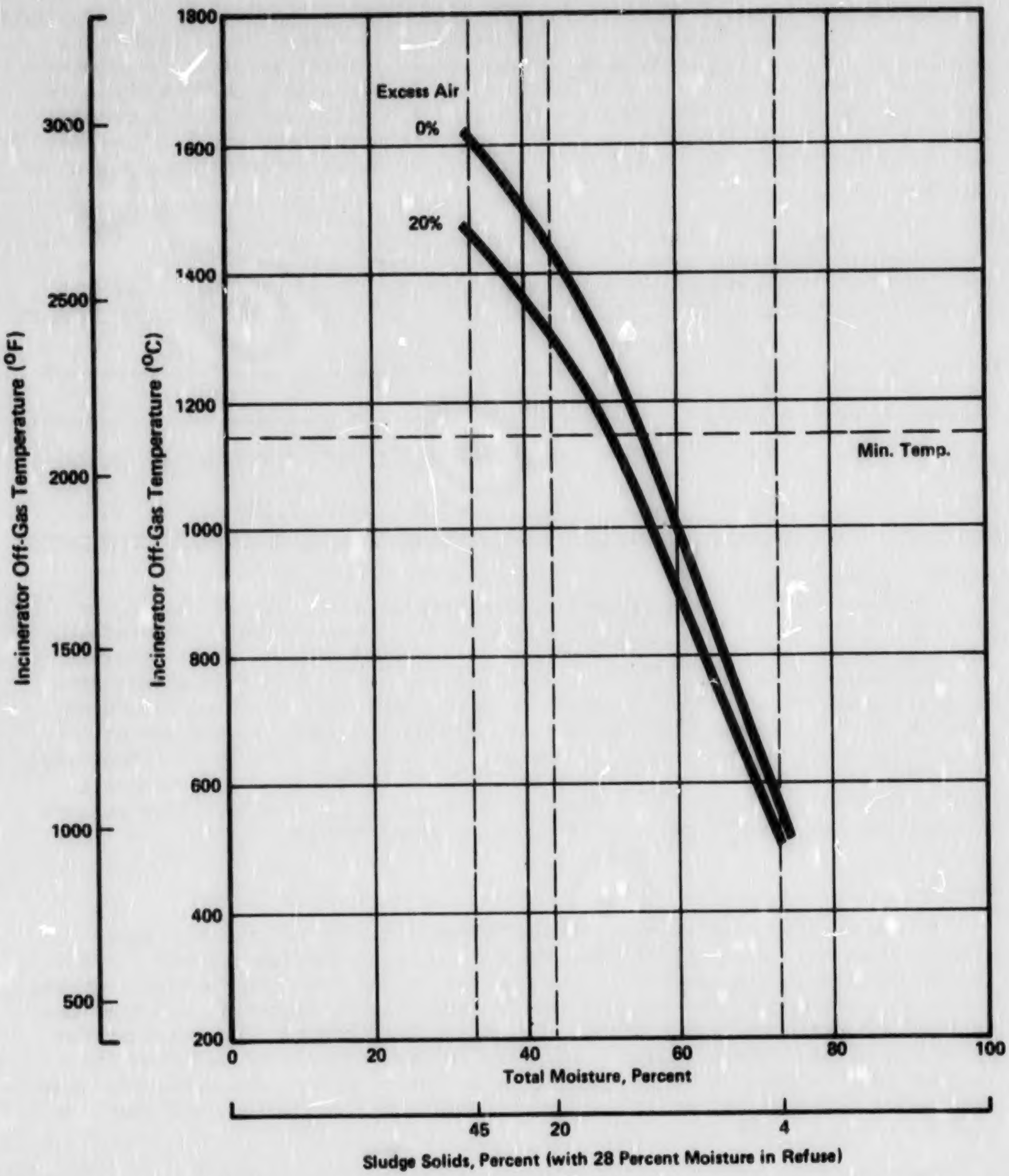


Figure 17. Pyrolysis Feasibility – 120% Equivalent Sludge.

refuse dropping from the shaft into the slag bed is difficult to control. At times the arch collapses, dumping unburned refuse onto the slag pool. Although temperatures in the pool are high, the oxygen-deficient atmosphere permits unburned refuse to leave the furnace.

The need for shredded rather than raw refuse must also be determined. At present, the Torrax process operates on a raw refuse feed, whereas Purox requires a finely shredded feed, with a nominal size of 7.6 cm (3 in.). A shredder plant adds significantly to the capital and operating cost of a co-incineration facility.

There are two plant design alternatives for a pyrolysis co-incineration facility, involving direct and indirect sludge predrying. Both shaft furnace systems produce a fuel gas with low heating value. This gas could be used in a direct-fired rotary dryer as described under Direct-Drying Co-Incineration. Dry sludge could then be fed into the shaft furnace, with an afterburner to insure odor destruction in the dryer off-gas. (See Figure 18 for the block flow diagram.) Although the sludge predrying increases the cost and complexity of the process, it is expected to improve the performance of the furnace. The same sludge moisture limitations as noted in the discussion of the heat and material balance apply to sludge predrying/pyrolysis co-incineration.

Sludge can also be predried using indirect techniques as described under Indirect-Drying Co-Incineration. In such a system, a boiler would be added to the pyrolysis plant, using the pyrolytic gas as fuel. Steam from refuse pyrolysis would be used to predry sludge in an indirect type of dryer. (See Figure 19 for the block flow diagram.) The advantage, over direct predrying, is the elimination of the afterburner. Water evaporated from the sludge is condensed in a barometric condenser and returned to the treatment plant. The small amount of purge air pulled into the dryer will be used as combustion air in the combustion of the pyrolysis gas.

Effect of Size

The effect of size on the feasibility of the pyrolysis co-incineration process is difficult to assess, since commercial plants have not yet been constructed. Torrax pilot facilities, 68 metric tons (75 tons) per day, have been successfully operated for extended periods. Thus, a pyrolysis co-incineration plant could serve a community with a population as small as 55,000. However, there are questions as to whether it would be economically feasible for a municipal authority to build and operate such a small plant. The present Purox demonstration plant in South Charleston, W. Virginia has been operated continuously at 91 metric tons (100 tons) per day. Quite likely, the minimum practical size for a pyrolysis co-incineration plant will be 227 metric tons per day (250 tpd), i.e., about the same capacity of a refuse incinerator. A unit of this size would serve an area of about 150,000 people.

Heat Recovery

In the co-incineration process, refuse was described as a fuel which is burned to provide additional heat necessary to dry the sludge and thereby

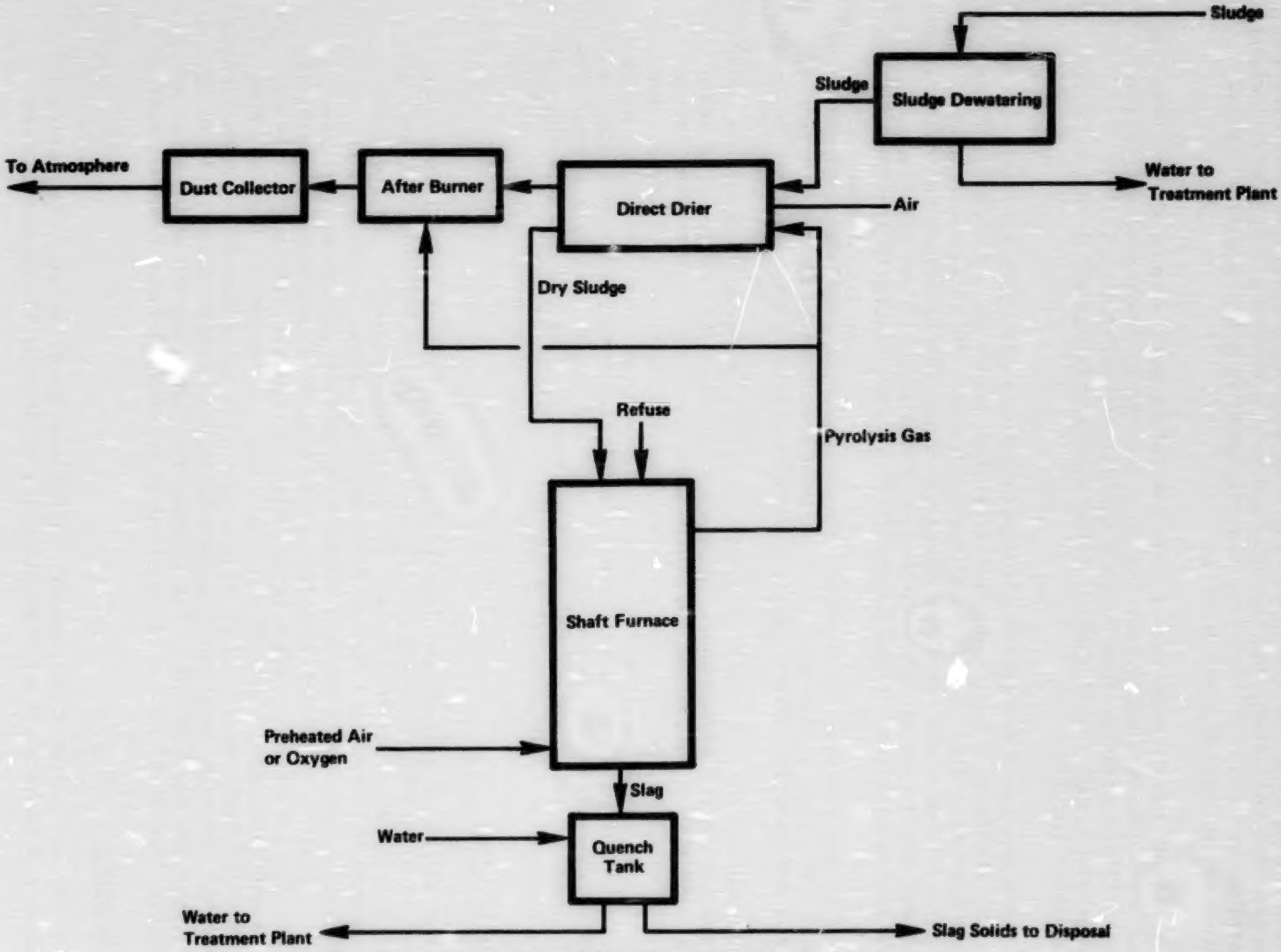

Sludge
Sludge
Sludge Dewatering
Water to
Treatment Plant
To Atmosphere
Dust Collector
After Burner
Direct Drier
Air
Dry Sludge
Refuse
Pyrolysis Gas
Shaft Furnace
Preheated Air
or Oxygen
Slag
Water
Quench
Tank
Water to
Treatment Plant
Slag Solids to Disposal

Figure 18. Pyrolysis Co-Incineration with Direct Sludge Pre-Drying — Process Flow Sheet.

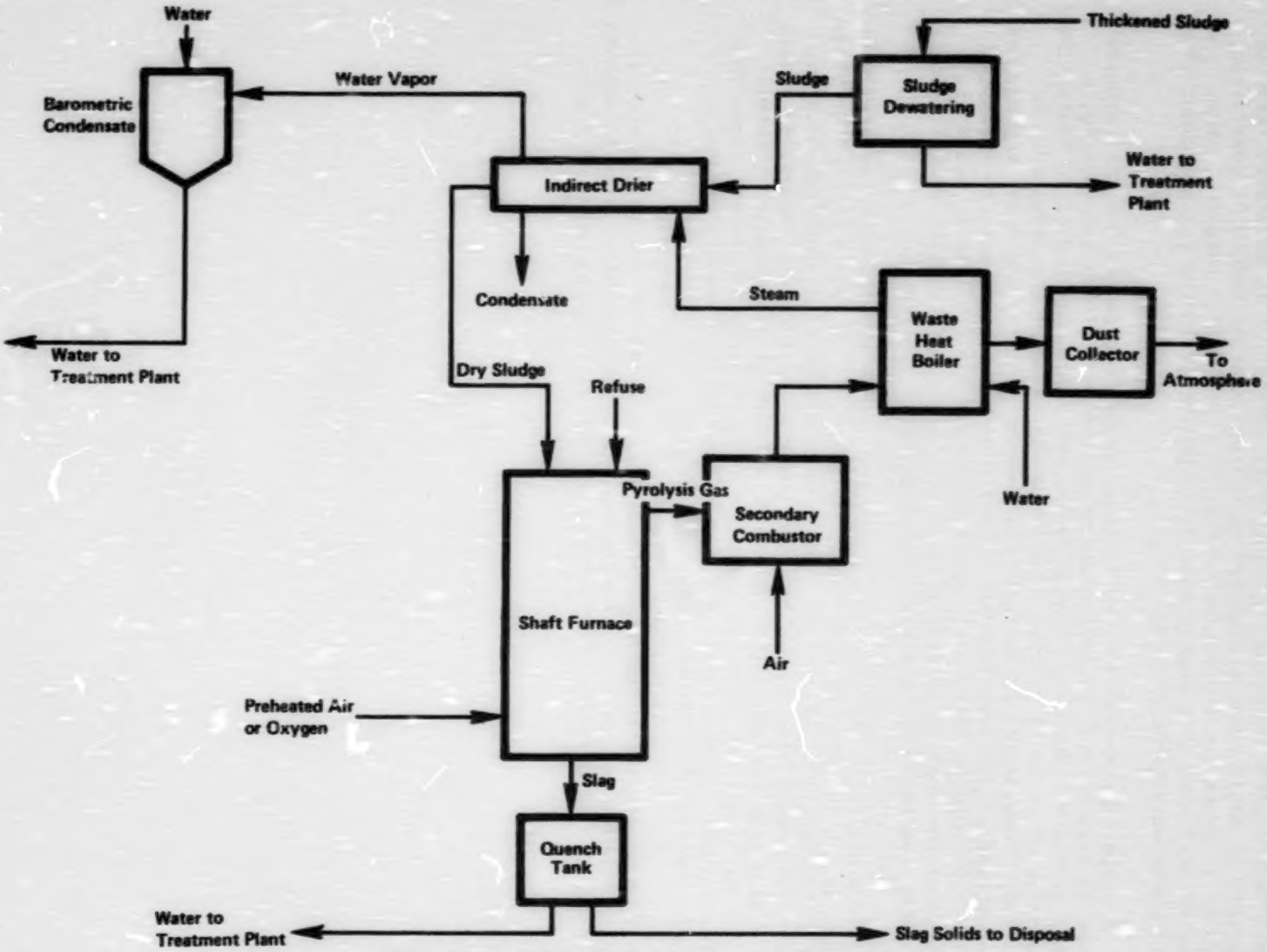

Water
Barometric Condensate
Water Vapor
Sludge
Thickened Sludge
Sludge Dewatering
Indirect Drier
Water to Treatment Plant
Condensate
Steam
Waste Heat Boiler
Dust Collector
To Atmosphere
Water to Treatment Plant
Dry Sludge
Refuse
Pyrolysis Gas
Secondary Combustor
Water
Shaft Furnace
Air
Preheated Air or Oxygen
Slag
Quench Tank
Water to Treatment Plant
Slag Solids to Disposal

Figure 19. Pyrolysis Co-Incineration with Indirect Pre-Drying – Process Flow Sheet.

permit incineration to occur. If refuse is considered as an energy resource, a variety of other uses in addition to co-incineration should be considered. While it is premature to consider refuse as a "valuable" resource, other means of utilizing this energy should be considered in the establishment of a solid waste management program.

A number of systems are available or under development for the recovery of energy from refuse, including steam-generating incinerators, pyrolysis plants producing gaseous or liquid fuels, and refuse-derived solid fuels. Heat recoveries of up to 70 percent of the heating value of the refuse can be obtained. However, it is unlikely that co-incineration and heat recovery can be practiced at the same facility. Co-incineration by direct pre-drying, indirect pre-drying, and multiple-hearth techniques requires a substantial portion of the fuel value available in the refuse. Pyrolysis, with its low air rate, may be compatible with energy recovery systems.

In addition to the thermodynamics, the logistics of energy markets, with regard to the location of a co-incineration plant, present a serious problem. The co-incineration facility must be located within sludge-pumping distance of the wastewater treatment plant. It would be fortuitous, indeed, to locate a viable energy market in the immediate vicinity of a wastewater treatment plant. Even with new wastewater treatment facilities, conditions other than energy markets (such as gravity flow and pumping requirements) normally dictate the location for the treatment plant.

We must therefore conclude that co-incineration and energy recovery are mutually exclusive, in most situations. A case-by-case study will be necessary to determine the potential for energy recovery at a co-incineration plant.

SECTION VI

AIR POLLUTION ASPECTS

CHARACTERISTICS OF EMISSIONS

The potential air pollutant emissions from the incineration of mixed municipal refuse (MMR) and/or municipal sewage sludge (MSS) fall into three distinct categories:

Combustible gases or vapors (carbon monoxide, hydrocarbons, odorous organics).

Particulates (ash, unburned carbon, and metallic fumes or oxides).

Inorganic gases (especially, NO_x, SO_2, HCl, and HF).

In any combustion process, it is necessary to design and operate the system to provide combustion conditions which will assure oxidation of the combustible gases and vapors to yield an innocuous and essentially odor-free effluent flue gas. Classically, the design and operating parameters of concern are referred to as the "three T's"--time, temperature, and turbulence. They relate to assuring that combustible and oxidant are intimately mixed at a temperature at which oxidation reactions are rapid, i.e. above 760°C (1,400°F), long enough for the reactions to proceed to completion.

The presence of detectable quantities of carbon monoxide in the flue gas has been proposed as an indicator of combustion efficiency. Niessen and Sarofim[1] have stated, "If turbulence above the fuel bed is high enough to provide perfect mixing, no CO should be found in the exit gases." They also state, "Based on the well stirred reactor studies, it is also expected that, because CO burns so much slower than other fuel elements, carbon monoxide will be detected in larger quantities than hydrocarbons in incompletely-burned flue gases." Incinerators have often been cited as sources of odorous emissions, but these are controllable by proper design and operation of the equipment to insure burnout of odorous compounds before the exhaust gases are vented. Proper design of the furnace system and consistent, careful operator control of the combustion process are the essential elements of the indicated route to abatement of combustible gas and vapor emissions.

Particulate emissions from an incinerator are primarily a function of the design and operation of the furnace system. The designer's furnace configuration and use of primary and secondary air establish the incinerator's basic performance capability. Within the limits set by the designer, the operator can significantly influence indinerator performance. When less than ideal combustion conditions exist because of design constraints or faulty operator control of the combustion process, the quantity of particulates emitted will increase (as will the combustible content of the fly ash).

Incinerator particulate emissions are also a function of the characteristics of the wastes fed to the incinerator. An increase in the quantity of fine material fed to the incinerator will increase the emission rate for any given incinerator system. Similarly, an increase in the volatile inorganic content of the feed will increase the quantity of fumes that are produced when the volatile materials condense.

The third type of air pollutant emitted from a combustion process includes the oxides of sulfur and nitrogen, plus the halogen acids. The potential emissions of sulfur oxides and halogen acids are directly related to the quantity of incompletely oxidized sulfur (sulfides, elemental sulfur, sulfites and organo-sulfur compounds) and organic halogens present in the MMR and MSS being burned. Some of these materials do not exit with the furnace flue gases, because they may react with the incinerator ash and pass out of the system with the incinerator residue.[2] The nitrogen oxides are formed in the flame, from the nitrogen present in the combustion air or in the material being burned. Lower flame temperatures and low excess-air levels decrease the amount of nitrogen oxide in the flue gases, but deliberate efforts to minimize nitrogen oxide formation may contribute to higher quantities of combustible carbon monoxide and increase the carbon content of the fly ash.

EMISSION REGULATIONS

Separate performance standards controlling the emissions from refuse and sludge incinerators have been promulgated by the federal government. Current (1975) federal emission standards limit the discharge of particulates, but do not regulate the discharge of the combustible or inorganic gases that may be produced by the incineration of refuse and sludge. Emission limitations for refuse incinerators, published in the Federal Register on 23 December 1971,[3] include "no owner or operator subject to the provisions of this part shall discharge or cause the discharge into the atmosphere of particulate matter which is in excess of 0.18 g/NM^3 (0.08 gr/scf) corrected to 12 percent CO_2, maximum 2-hour average." Federal standards for sludge incinerator emissions published in the Federal Register on 8 March 1974[4] read as follows:

> "No operator of any sewage sludge incinerator subject to the provisions of this sub-part shall discharge or cause the discharge into the atmosphere of:
>
> "1. Particulate matter at a rate in excess of 0.65 g/kg dry sludge input (1.30 lb/ton dry sludge input).
>
> "2. Any gases which exhibit 20% capacity or greater. Where the presence of uncombined water is the only reason for failure to meet the requirements of this paragraph, such failure shall not be a violation of this section."

The emission standard for refuse incinerators is based on units of concentration, whereas the standard for sludge incinerators is based on units of mass. The reasons for this difference in national emissions standards are complex, but basically recognize the operating practices and feasible procedures involved with separate incineration of refuse and sludge. For instance, the Federal EPA considered setting emission standards for refuse incinerators on a mass basis, but rejected it because it concluded that there was no reliable method to determine the actual incinerator firing rate. While it is conventional practice to weigh MMR upon receipt at the incinerator plant, no domestic incinerator was at that time equipped to weigh the material fed to the furnaces on a continuous and reliable basis.

In the case of sludge incineration, the original proposed regulation was based on units of concentration, but was changed to units of mass for two principal reasons. First, dilution does occur, and is significant. Second, the control devices normally used on sludge incinerators--wet scrubbers--absorb some of the CO_2 present in the gases discharged to the atmosphere. This, as well as the CO_2 contributed by auxiliary fuel, alters the gas composition and precludes the relatively simple correction of results to a reference basis such as 12 percent CO_2. Because of this, the determination of the amount of dilution could then prove difficult. Further information on the rationale behind setting the Federal standards is contained in the background documents which were published in connection with the Federal new-source performance standards.

Available information on the species of air pollutants permitted from refuse incinerators has been summarized in a paper by Smith.[5] Similar information on sludge incinerator emissions has been summarized in an EPA Technology Transfer Seminar publication.[6]

Based upon available data,[3,4] the efficiency of particulate control devices required to meet the Federal emissions standards is 90 to 95 percent for refuse incinerators, and 96.6 to 99.6 percent to meet sewage sludge incinerator emission standards. The "Standards of performance for New Stationary Sources" were authorized in Section III of the Clean Air Act Amendments of 1970: "The overriding purpose of this section is to prevent the general occurrence of new air pollution problems by requiring the installation of the best controls during initial construction, when the installation of such controls is least expensive."[7] The term "standard of performance" is defined as "a standard for emissions of air pollutants which reflects the degree of emission limitation achievable through the application of the best system of emission reduction which (taking into account the cost of achieving such reduction) the administrator determines has been adequately demonstrated." Under the terms of the Clean Air Act Amendments, a state or local jurisdiction may adopt more stringent emission limitations where it is necessary, in order to achieve national ambient air quality standards. Maryland is one jurisdiction that has adopted a more stringent refuse incinerator emission standard, 0.07 g/NM^3 (0.03 gr/scf), which is considerably lower than the federally mandated 0.18 g/NM^3 (0.08 gr/scf).

CONTROL OPTIONS — MSS OR MMR SYSTEMS

High-efficiency control devices are obviously necessary to meet the Federal standards or the more stringent state or local standards that may be enacted. The devices that are capable of attaining the performance required by regulatory action are electrostatic precipitators, wet scrubbers, and fabric filters (baghouses). All three of these devices have been used to control the emissions from refuse incineration.

By far the most commonly installed on new MMR systems is the electrostatic precipitator. In fact, the Federal emissions standards for refuse incinerators were based on the degree of control achieved with electrostatic precipitators.

The most popular high-efficiency collector in use on sludge incinerators is the wet scrubber. Fife[8] reports an electrostatic precipitator (ESP) installation on a municipal sewage treatment plant sludge incinerator system in the 1940's; many problems were created by the sticky nature of the sludge fly ash. Precipitators in such circumstances have since been replaced with wet scrubbers. In Japan, however, the emission standard is based on ESP-equipped plants.

Baghouses have been tried on refuse incinerators, both experimentally and commercially, but never widely applied or advocated. To our knowledge, they have not been used in sludge incineration practice.

Fife also provides a list of important considerations that have led to the reported preference for electrostatic precipitators on refuse incinerators:

> "1. The equipment does not produce a wastewater stream requiring treatment prior to disposal.
>
> "2. The equipment operates at a lower pressure drop than any other high-efficiency type of gas cleaning equipment, at a very significant saving in power. For 20-year life installations, the power saving may well justify the extra cost of a precipitator in comparison with other systems.
>
> "3. The equipment does not produce the heavy steam plume normal to wet scrubbers. This may be a very real aesthetic advantage, or may eliminate the need for complex and expensive plume suppression facilities.
>
> "4. The equipment operates dry, and may not require special construction to resist corrosion, particularly where continuous operation is contemplated."

Precipitators, however, are ineffective in controlling gaseous pollutants such as carbon monoxide, the oxides of nitrogen and sulfur, and hydrogen chloride. The concentrations of these pollutants are low relative to most other combustion sources and the net quantities emitted from refuse/sludge incineration are usually insignificant in the total emission inventory of a region. Lastly, the high stack gas temperatures associated with ESP control, 230°C (450°F), contribute to rapid atmospheric dilution of the gaseous contaminants.

If gaseous pollutant control is a requirement of a local regulatory agency (no such requirement now exists in the New Source Performance Standards) or is felt to be important by the design engineer (e.g. if an unusually high concentration of PVC or other halogen acid source was expected), the ESP performance goals should be thoroughly discussed.

The primary alternative is a wet scrubber arranged to use an alkaline solution and designed to remove gaseous pollutants in addition to particulate pollutants. The experience to date with the use of scrubbers on MMR incinerator applications has been that the acid gases which are present create a very corrosive environment within the scrubber, thus putting a severe constraint on material selection. As the collection equipment generally is located upstream of the induced-draft fan and discharge stack, it is probably necessary that all the materials used downstream of the scrubber be constructed of costly, corrosion-resistant materials. Finally, unless stack reheat is practiced, there is always the possibility of condensation and the consequent emission of "acid rain" from the incinerator stack.

Another control option is the fabric filter or baghouse, where it would be possible and practical to use a dry adsorbent material to remove the acid gases from the gas stream. Dry adsorption in this fashion may some day be developed to the point of being commercially applicable; it is not now a proven control technique.

Present state-of-the-art considerations indicate that the order of preference for control of air pollutants from MMR incinerators is 1) electrostatic precipitators, 2) wet scrubbers, and 3) baghouses. For sewage sludge incinerators the present state of the art favors the use of wet scrubbers, as neither electrostatic precipitators nor fabric filters have been successfully applied to this service in the United States. ESP's have been sucessfully applied in Japan, however, and their performance has formed the basis for setting emission standards.

IMPACT OF CO-INCINERATION ON EMISSIONS

Of the three emission categories, only particulates are regulated by Federal emission standards. Stack-gas opacity is an indirect method of assessing particulate emissions, and only the MSS incinerator regulations include an opacity requirement. Inorganic gas emissions are a function of waste characteristics, with the exception of the nitrogen oxides, where combustion conditions do affect the conversion of atmospheric nitrogen to NO_x.

The available data,[5,6] although inadequate for full assessment of the impact of co-incineration on the emissions of inorganic gases, seem to indicate that inorganic gaseous emissions from MSS incineration are less than or equal to comparable emissions from the incineration of MMR alone. Because inorganic gas emissions from incineration are not now regulated and since the state of the art regarding control of such emissions is uncertain, further discussion of this category of emissions is not warranted.

To prevent the release of combustible gases and vapors to the environment, two conditions must be met. First, all combustion air and all vapors evaporated from the MMR and MSS must pass into an active combustion zone. Second, the combustion process must be completed in the active combustion zone. The design and operating objectives for the incineration of MMR or MSS and for the co-incineration of MMR and MSS are identical insofar as the potential emissions of combustible gases and vapors are concerned. In all cases, the combustion system must be designed to insure completion of the combustion reactions. (The electrostatic precipitator problem reported by Fife[8] can be attributed to the condensation of tar vapors, indicating that these gases bypassed the active combustion zone.)

The effect of co-incineration on furnace particulate emissions cannot be easily generalized, since the furnace design and method of handling the MMR and MSS are basic variables. Nevertheless, all the co-incineration techniques reviewed will require the use of high-efficiency control equipment to meet present Federal standards of performance. Each of the co-incineration techniques discussed in Section IV has a different emission potential.

Where the MSS is first dried and then burned in an MMR furnace, an increase in particulate emissions from the furnace can be expected, because the ash remaining after MSS solids are burned will undoubtedly be fine and easily entrained in the flue gases. If all the MSS ash becomes fly ash, the impact of co-incineration on furnace emissions can be assessed for a given ratio of MMR and MSS (see Feasibility Study, Section V). When MMR emissions are 10 kg/metric ton (20 lbs/ton) of refuse and MSS emissions are 150 kg/metric ton (300 lbs/ton) of dry solids, the furnace particulate emission rate would roughly double. Therefore, in order to meet Federal particulate emission standards of performance for MMR incinerators, the efficiency of the control device must be increased from the 90-95 percent range to a 95-97.5 percent range.

The particulate emission potential of multiple-hearth furnaces burning sludge, refuse, or both is poorly documented. Similarly, data for assessment of the emission potential of the pyrolysis technique of co-incineration are not available. The following discussion, however, indicates the probable particulate emissions from these types of operation.

In a multiple-hearth unit, the wastes cascade from hearth to hearth. When they cascade from an in-hearth to an out-hearth (See Figure 2, Section III), the falling wastes are exposed to a cross current of gas flow. When the wastes fall through the drop holes from an out-hearth to an in-hearth, they pass countercurrent to the rising stream of flue gases. The net result is that the particulate fines are exposed to an elutriating gas stream as the wastes are transferred from hearth to hearth in the furnace and the flue gases pass over the wastes. The probable effect on co-incineration furnace emissions is to make the particulate emissions greater than those experienced with sludge incineration alone. Since collection efficiencies of 96.6 to 99.6 percent were considered necessary to meet Federal standards of performance for any sludge incinerators, increase in inlet loading would make it difficult to comply with promulgated emission limits when a multiple-hearth furnace is used to co-incinerate MMR and MSS.

The pyrolysis (shaft) furnace is the most difficult to assess, because so very little information is available. We have to speculate that co-incineration will increase the quantity of particulate emissions, because all the combustion and the level of emissions compared to conventional refuse incinerators are unknown.

In all of these cases, the furnace emission rates are expected to increase over those that have been reported when burning only MMR or MSS. The actual increase in particulate emission rates is moot, and establishment of these levels should be a part of any demonstration project. Estimates of uncontrolled emission rates for both separate and combined incineration are shown in Table 12. For demonstration purposes, we suggest that the level of control attainable with the control equipment already installed be deemed acceptable. For new projects incorporating co-incineration, we suggest that the least stringent of present regulations be applied until actual performance data can be obtained.

CONTROLS REQUIRED FOR CO-INCINERATION

The Clean Air Act as amended clearly mandates the use of the best practicable and demonstrated control technology that can be economically justified. Where MMR and MSS are being burned together, on an equal-population basis, the amount of refuse being processed totally dominates the dry sludge solids resulting from primary and secondary treatment of municipal sewage. On such a basis, refuse quantities would account for 93 percent of the incinerator feed; therefore, where two Federal standards of performance are involved, the co-incineration device should probably be considered as a refuse incinerator and be required to meet applicable codes for refuse incinerator emissions.

Federal standards of performance are less stringent for MMR incineration; however, since the emission potential of joint MMR-MSS incineration is higher than MMR incineration alone, the collection efficiency of control devices will have to be increased in order to meet MMR emission regulations. If co-incineration plants were required to meet MSS incinerator regulations, there is reason to believe that the performance required of the control device can be attained at only a modest increase in capital cost and a negligible increase in operating cost (for ESP systems).

FINAL CONSIDERATIONS

Concern has been expressed about the emissions from incineration of toxic organic compounds and potentially hazardous metals. Available data[6] indicate that toxic organics can be destroyed during incineration and that the bulk of the metals, with the exception of mercury, can be removed by the air pollution control device. The sole exception, mercury, is present in both MMR and MSS; consequently, potential mercury emissions should be determined in relation to the allowable ambient concentrations at the time of design.

TABLE 12. ESTIMATED AIR POLLUTANT EMISSIONS FROM REFUSE, SLUDGE AND COMBINED INCINERATION

	Incinerator Uncontrolled Emission Factor kg/metric ton (lb/ton)^{1,2}					Control Technology Typical U.S. Practice (1970) (Best Available Technology) (1976)	
			Co-incineration (estimates)^{6}				
Pollutant	Conventional Solid Waste	Multiple Hearth Sludge	Dry Sludge Injection	Mult. Hearth	Pyrolysis	Solid Waste	Sludge
Particulate	15.0 (30.0)	16.5 (33.0)	22 (44)	18 (36)	10 (20)	Dry or Wet Baffles ESP	Low P Scrubber Venturi Scrubber
SO_x	1.3 (2.5)	0.5 (1.0)	---	1.2(2.4)	---	none^{3} N/A^{4}	none^{3} N/A^{4}
NO_x	1.0 (2.0)	2.5 (5.0)	---	1 (2)	nil	none^{3} N/A^{4}	none^{3} N/A^{4}
Hydrocarbons	0.8 (1.5)	0.5 (1.0)	---	0.5(1)	N/A^{7}	none^{3,4,5} N/A^{5}	none^{3,4,5} N/A^{5}
Carbon Monoxide	17.5 (35.0)	0.0 (0.0)	16 (32)	2.5(5)	N/A^{7}	none N/A^{5}	none^{3,4,5} N/A^{5}
Heavy Metal Oxides	small	small		small		Dry or Wet Baffles ESP^{4}	Low P Scrubber ESP or Venturi Scrubber^{4}

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[1] Source: Supplement No. 4 for Compilation of Air Pollutant Emission Factors, EPA Report AP-42 (1975).

[2] Emission factor is for dry sludge solids and as-received refuse.

[3] "None" means that control of the pollutant is not the primary concern of the equipment specifications.

[4] New Source Performance Standards relate only to "dry particulate" (Hg emission for sludge-burning is limited to 3200 grams/day).

[5] Control of combustible pollutants is accomplished by maintaining a proper combustion environment rather than by tail gas control systems.

[6] At equivalent domestic populations of refuse and sludge.

[7] Not applicable since product fuel gas is sought.

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SECTION VII

ECONOMIC CONSIDERATIONS

BACKGROUND AND METHODOLOGY

Plant Size and Other Design Considerations

There are several technically feasible co-incineration techniques, each of which can be expected to have advantages in specific circumstances related to the plans for a given area. However, selection of the appropriate co-incineration system also requires careful consideration of the economics involved. System economics will therefore be developed for a given primary-secondary wastewater treatment plant in the size range of 75,700-378,500 cu m/day (20-100 mgd) capacity.

The wastewater treatment plant selected as the basis for calculation of MSS and MMR incineration is the Piscataway plant of the Washington Suburban Sanitary Commission. This 114,000 cu m/day (30 mgd) plant is located south of Washington, D.C. in Prince Georges County, Maryland of Piscataway Creek, which discharges to the Potomac River. Piscataway provides primary and secondary treatment, and has contracted for the construction of tertiary treatment facilities. For the purposes of this economic analysis, however, only the sludge generated by primary-secondary treatment steps at design plant capacity will be considered.

The sludge generated at Piscataway is based upon an influent flow of 114,000 cu m/day (30 mgd) and Biochemical Oxygen Demand and Suspended Solids loadings of 23,000 kg/day (50,000 lb/day) each. The sludge is dewatered by vacuum filtration to a solids concentration of 20 percent. Lime, polymers, and ferric chloride are used to condition the sludge before dewatering. The design sludge quantity is 28,000 kg (61,700 lb) dry solids per day, or 140,000 kg (308,500 lb) wet sludge per day at 20 percent solids.

The population of Prince Georges County was 661,192 on 1 April 1970. At 1.24 kg/capita/day (2.74 lb/capita/day), the domestic MMR generated in the county is about 820,000 kg/day (1,810,000 lbs/day). Note that not all the wastewater sources in the county discharge to the Piscataway treatment plant at the present time. For a valid assessment of co-incineration economics, it is inappropriate, therefore, to include all the refuse generated by county residents, when less than half of the sludge quantity generated in the same region is involved. To provide a more reasonable basis for the economic analysis, we equate the two unit factors: 1.24 kg (2.74 lb) of MMR per capita per day and 379 l/capita/day (100 gpcd) of wastewater. Consequently, with a wastewater flow of 114,000 cu m/day (30 mgd), the corresponding refuse generation is 373,000 kg (822,000 lb) of MMR per day.

The refuse-to-sludge ratio, on this basis, is 2.67:1. Since the feasibility study showed that co-incineration was practical at a refuse-to-sludge ratio of 2.43:1 (or higher) with 20 percent solids in the dewatered sludge, the proportions are considered satisfactory. Since the county population will increase by 1980 and the Piscataway plant is not expected to reach full capacity unitl after 1980, there is clearly sufficient refuse available for the practice of co-incineration without using the refuse generated by commercial, institutional or industrial sources. The final refuse mix might include refuse from these sources, but those decisions need not be made for purposes of this economic analysis.

With a daily sludge generation rate of 140,000 kg (308,000 lb) of dewatered sludge per day and using 373,000 kg (822,000 lb) per day of MMR to provide the necessary additional heat, we can compute disposal needs in terms of a 6-day work week for 50 weeks per year. The MSS disposal rate is thus 170 metric tons/day (187 tpd) using 453 metric tons/day (499 tpd) of MMR for a total disposal rate of 622 metric tons/day (686 tpd).

For two of the co-incineration techniques, the dewatered sludge is first processed through direct or indirect contact dryers, and only the dried solids are added to the main furnace. The dried sludge, preferably, is blown into the furnace and burns largely in suspension. Therefore, the refuse incinerator is required to handle only 453 metric tons/day (499 tpd) of MMR over the grate surface. Two 227 metric ton/day (250 tpd) furnaces would be a marginal selection, because refuse is a highly variable fuel. Two 272-metric ton/day (300 tpd) furnaces, however, would provide an incinerator plant capacity with a 20 percent safety factor over required MMR capacity. Good practice dictates designing the incinerators for a high-heat-release refuse. In this case we have sized the furnaces for a heat release rate of 71×10^6 kg-cal (280×10^6 Btu) per hour, or 2,830 kg-cal/kg (5,600 Btu/lb) of refuse. The sludge driers were also designed with a 20 percent safety factor, over the expected daily generation rate. Each sludge drying circuit will handle 203 metric tons/day (224 tpd) of 20% solids sludge.

The two other co-incineration techniques combine the MMR and MSS before feeding the furnace. In order to make these two systems (Torrax and Multiple-Hearth) compatible with the first two systems they will be sized for the same heat release rate of 71×10^6 kg-cal/hr (280×10^6 Btu/hr). The shaft furnace (Torrax) has been demonstrated on MMR as the basic feed material, but the multiple-hearth furnace has not been used to incinerate MMR without feeding MSS with the MMR. The feasibility of using a multiple-hearth furnace to incinerate MMR alone is thus suspect, but by sizing the various furnace systems on a common heat release basis, we provide for equivalent air and gas handling systems.

The design basis used in the following cost estimates is as follows:

Refuse -- 544 metric tons/day (600 tpd)
Sludge -- 203 metric tons/day (224 tpd)
Total for Co-Incineration -- 747 metric tons/day (824 tpd)

Sources of Cost Information

Capital costs reported in this section are based on Weston's experience in the design and reconstruction of the City of Baltimore Incinerator No. 4. Adjustments in costs have been made, however, to account for items such as foundations already in place. Cost figures have been updated to mid-1975. Cost estimates for various types of equipment were supplied by the following manufacturers:

Enviro Tech Corporation Menlo Park, California	Multiple-Hearth Furnaces
Combustion Engineering, Inc. Chicago, Illinois	Rotary Driers
Bethlehem Corp. Bethlehem, Pennsylvania	Indirect Driers
Williams, Co. St. Louis, Missouri	Shredders
Carborundum Environmental Systems, Inc. Hagerstown, Maryland	Pyrolysis Plants

Additions were made to quoted prices, where appropriate, to include cost of construction and installation, materials-handling equipment, auxiliaries, and buildings; these additions are based on estimates prepared by the Weston staff. As with any construction cost estimates made at the conceptual stage, accuracy will be in the range of ± 25 percent.

The accuracy of operating cost estimates is better then that of construction estimates, even when made at an early stage. Manpower requirements were made with first-hand knowledge of the staffing in Baltimore and Philadelphia. Power and water consumption costs were based on design calculations or on vendor's information. Residual disposal costs were based on Weston's experience in the design and evaluation of land disposal sites throughout the U.S. Only maintenance and overhead were calculated as fixed percentages of equipment, a widely accepted method of estimating maintenance cost for comparison of alternative approaches at the feasibility level. Accuracy of the operating cost estimate should be in the range of ± 10 percent.

Discussion of Cost Components

Capital and operating costs have been developed for refuse and sludge incineration separately, and for the four co-incineration techniques examined in the feasibility study. A figure representing the total disposal cost per ton of refuse/sludge was also determined. While all facets of the economic analysis are significant, it is the cost-per-ton of material incinerated which represents the truest picture of co-incineration cost vs. separate incineration of sludge and refuse.

Capital Costs--

Capital costs include: equipment, labor and materials for installation, construction overhead, and contingency. Note that the contingency (at 15 percent) is added on individual equipment modules, rather than as a lump sum on the total construction cost. Costs for additional capital items are then added to the direct construction costs. The category designated as Design, Construction Management and Start-up also includes preparation of manuals, permits, and other engineering functions, and is estimated at 15 percent of the direct construction cost. A land cost of $124,000/hectare ($50,000 per acre) was assumed, noting that the co-incineration plant will be located near the water treatment plant on prime waterfront property. Legal fees throughout the entire life of the projected are placed at 3 percent of direct construction cost. The standard 3 percent bond discount is also included in the total monies requiring capitalization. Bond life is taken as 20 years, at 7 percent annual interest.

Operating Costs--

Typical operating costs (mid-1975) were combined to provide the Direct Operating Cost values used in the comparison. Manpower includes four full shifts for 7-day per week operation, plus supervision and maintenance. Salary/overhead ranged from $10,000 to $20,000 per year, with operators and senior maintenance men at $17,000 per year. An additional 20 percent is added to the total manpower cost to cover overtime, vacations, holidays, etc. Power costs are based on 13,000-volt service, at $0.027 per kwh. Water and sewer costs are combined at $0.10/cu m ($0.37/thousand gal). Fuel costs are based on No. 2 fuel oil, at $0.10/liter ($0.379/gal), delivered in 15 cu m (4,000 gal) quantities. (The variability of fuel usage eliminates contract delivery and results in higher fuel prices.) Maintenance cost is estimated at 2.5 percent of installed equipment cost. Plant operating overhead, estimated at 1 percent of installed equipment cost, includes insurance, chemicals, expendibles, janitorial service, etc. Residue disposal cost is based on off-site disposal, by private contractor. A tipping fee of $2.20 per metric ton ($2/ton) (solids) and a transportation cost of $0.069 per metric ton-km ($0.10 per ton-mile) and a 32-km (20 mi) haul bring total residue disposal cost to $4.40 per metric ton ($4.00 per ton).

BASIC COST CALCULATIONS

A series of three cost estimates (Construction Cost, Total Facility Capital Cost, and Operating Cost) was prepared for each of six equipment systems:

1. Modern Refuse Incinerator--540 metric ton/day (600 tpd) capacity
2. Multiple-Hearth Sludge Incinerator--203 metric ton/day (224 tpd) capacity

3. Co-Incineration/Rotary Sludge Drier

4. Co-Incineration/Indirect Sludge Drier

5. Co-Incineration/Multiple-Hearth Furnace

6. Co-Incineration/Pyrolysis.

In each of the co-incineration systems, the refuse capacity was 540 metric tons (600 tons) and the Sludge capacity was 204 metric tons (224 tons) per day.

These estimates, presented in Tables 13 through 30, are the basic data used in the analysis of co-incineration costs.

ANALYSIS OF CO-INCINERATION COSTS

Comparison of Co-Incineration and Separate Incineration

The principal conclusion to be drawn from the economic analysis is that every cost factor (Capital, Direct Operating, Total Annual Cost) favors co-incineration, by any of the four techniques; over separate incineration of sludge and refuse.

Capital Cost--

Capital cost for each of the four co-incineration techniques was lower than separate incineration by one to two million dollars. While the magnitude of the cost difference will vary as the capacity of the plant changes from the capacity used in this analysis, percent differences will remain approximately the same. Table 31 lists the percent capital cost reduction to be expected by co-incineration, based on comparison with the combined capital cost of separate incineration facilities.

The lower capital cost is obtained primarily from the replacement of the sludge incinerator and related equipment (scrubbers, fans, etc.) by less expensive sludge-drying equipment in the pre-drying techniques and from incremental capacity (low cost) in the direct sludge incineration techniques. Sludge pre-drying is low in capital cost compared with sludge incineration. The dry sludge solids feed to the incinerator represents an increase of only five percent in the total quantity of solids handled, and an even smaller percentage on the basis of combustible solids. Since dry sludge solids are burned in suspension, the actual impact on the refuse incinerator size is almost negligible. In the direct sludge incineration techniques, on the other hand, the sludge is actually pre-dried within the incinerator unit. Direct-drier and multiple-hearth techniques also show lower capital costs than the indirect-drier and pyrolysis techniques; the latter require the addition of steam-generating equipment, plus auxiliaries. Of course, all differences in capital cost are translated directly into annual operating costs (cost of owning) by application of the capital recovery factor.

TABLE 13. CONSTRUCTION COST--MODERN REFUSE INCINERATOR
(Design Capacity: 600 tpd; two-tpd units)*

Item	Cost
Two 300-tpd Units:	
Furnace & Combustion System	$1,462,000
Stack	306,000
Fans/Ductwork	424,000
Piping	469,000
Electrical/Instrumentation	681,000
Conveyors	711,000
Sub-Total	$4,053,000
Two Electrostatic Precipitators	2,420,000
Two Bridge Cranes	1,000,000
Building; including Foundations, Pit, Office Space, Scales	7,818,000
Direct Construction Cost	$15,291,000
Direct Construction Cost per tpd (Design Cap.)	$25,500

* 1 ton = 0.907 metric ton

TABLE 14. TOTAL FACILITY CAPITAL COST--MODERN REFUSE INCINERATOR
(Design Capacity: 600 tpd)*

Item	Cost
Direct Construction Cost (DCC)	$15,291,000
Design, Construction Management, Start-up (15% of DCC)	2,294,000
Land ($50,000/acre)	500,000
Legal Fees (3% of DCC)	459,000
Bond Discount Fee (3% of Total Cost)	556,000
Total Facility Cost	$19,100,000
Facility Cost per tpd (Design Cap.)	$31,800

* 1 ton = 0.907 metric ton

TABLE 15. OPERATING COST--MODERN REFUSE INCINERATOR
(Design Capacity: 600 tpd)

Item	Cost Per Ton *	Total Annual Cost
Manpower (38 Employees)	$ 4.16	$ 624,600
Power (845 kwh/hr)	1.09	164,000
Water(Sewer 420 gpm)	0.37	55,400
Auxiliary Fuel & Heating (18,400 gpy)	0.04	6,000
Maintenance (2.5% DCC)	2.55	382,300
Overhead (1% DCC)	1.02	152,900
Residue Disposal (150 tpd)	1.20	179,600
TOTAL OPERATING COST	$10.43	$1,564,900

* Based on throughput of 150,000. Divide by 0.907 to obtain cost per metric ton.

TABLE 16. CONSTRUCTION COST--MULTIPLE-HEARTH SLUDGE INCINERATOR
(Design Capacity: 224 tpd)

Item	Cost
One Multiple-Hearth Incinerator:	
Incinerator - 22 ft. diam x 8 hearth, including venturi scrubbers	$1,458,000
Fans/Ductwork	350,000
Piping	383,000
Electrical/Instrumentation	561,000
Conveyors/Ash Handling	583,000
Sub-Total	$3,335,000
Building	1,284,000
Oil Storage/Distribution	225,000
Direct Construction Cost	$4,844,000
Direct Construction Cost per tpd	$21,600

* 1 ton = 0.907 metric ton

TABLE 17. TOTAL FACILITY CAPITAL COST--MULTIPLE-HEARTH SLUDGE INCINERATOR
(Design Capacity: 224 tpd)*

Item	Cost
Direct Construction Cost (DCC)	$4,844,000
Design, Construction Management Start-Up (15% DCC)	727,000
Land ($50,000/acre)	150,000
Legal Fees (3% DCC)	145,000
Bond Discount (3% Total Cost)	176,000
Total Facility Cost	$6,042,000
Facility Cost per tpd (Design Cap.)	$27,000

* 1 ton = 0.907 metric ton

TABLE 18. OPERATING COST--MULTIPLE-HEARTH INCINERATOR
(Design Capacity: 224 tpd)

Item	Cost Per Ton *	Total Annual Cost
Manpower (24 employees)	$ 6.77	$ 379,200
Power (150 kwh/hr)	0.52	29,400
Water/Sewer (275 gpm)	0.78	44,000
Auxiliary Fuel & Heating (1,238,400 gal/year)	8.49	475,400
Maintenance (2.5% DCC)	2.06	115,400
Overhead (1% DCC)	0.82	46,100
Residue Disposal (11 tpd)	0.24	13,200
Total Operating Cost	$19.68	$1,102,700

* Based on throughput of 150,000. Divide by 0.907 to obtain cost per metric ton

TABLE 19. CONSTRUCTION COST--CO-INCINERATION/ROTARY SLUDGE DRYER
(Design Capacity: Refuse 600 tpd; Sludge 224 tpd)*

Item	Cost
Incinerator DCC (as in Table 20)	$15,291,000
Drier Circuit:	
Rotary Drier, Fan, Cyclone	$ 1,477,000
Ductwork	138,000
Conveyors & Pug Mill	278,000
Subtotal	1,893,000
Additional Building	1,370,000
Direct Construction Cost	$18,554,000
Direct Construction Cost Per tpd (Design Cap.)	$22,500

* 1 ton = 0.907 metric ton

TABLE 20. TOTAL FACILITY CAPITAL COST--CO-INCINERATION/ROTARY SLUDGE DRYER
(Design Capacity: Refuse 600 tpd; Sludge 224 tpd)*

Item	Cost
Incinerator DCC	$15,291,000
Dryer DCC	3,263,000
Total Installed Cost	$18,554,000
Design, Construction Management, Start-up (15% of DCC)	2,783,000
Land (50,000 per acre)	500,000
Legal Fees (3% DCC)	557,000
Bond Discount (3% Total Cost)	672,000
Total Facility Cost	$23,066,000
Facility Cost per tpd (Design Cap.)	$28,000

* 1 ton = 0.907 metric ton

TABLE 21. OPERATING COST--CO-INCINERATION/ROTARY SLUDGE DRYER
Design Capacity: Refuse 600 tpd; Sludge 224 tpd

Item	Cost Per Ton *	Total Annual Cost
Manpower (46 employees)	$ 3.61	$ 744,000
Power (1265 kwh/hr)	1.20	247,700
Water/Sewer (435 gpm)	0.29	59,700
Auxiliary Fuel & Heating (128,800 gpy)	0.20	41,200
Maintenance (2.5% DCC)	2.25	463,800
Overhead (1% DCC)	0.90	185,500
Residue Disposal (161 Ton/day)	.94	193,200
Total Operating Cost	$ 9.39	$1,935,100

* Based on throughput of:
Refuse -- 150,000 Tons Per Year
Sludge -- 56,000 Tons Per Year
Total -- 206,000 Tons Per Year
Divide by 0.907 to obtain cost per metric ton.

TABLE 22. CONSTRUCTION COST--CO-INCINERATION/INDIRECT SLUDGE DRYER
(Design Capacity: Refuse 600 tpd; Sludge 224 tpd)*

Item	Cost
Incinerator DCC	$17,031,000
Dryer Circuit	
Two Porcupine Dryers	
Model No. (2P-30 X 16)	1,106,000
Ductwork & Blower	87,000
Piping	132,000
Conveyors & Pug Mill	278,000
Subtotal	1,603,000
Additional Building	856,000
Direct Construction Cost	$19,490,000
Direct Construction Cost per tpd (Design Cap.)	$23,600

* 1 ton = 0.907 metric ton

TABLE 23. TOTAL FACILITY CAPITAL COST--CO-INCINERATION/INDIRECT SLUDGE DRYER (Design Capacity: Refuse 600 tpd; Sludge 224 tpd)*

Item	Cost
Incinerator DCC	$17,031,000
Dryer DCC	2,459,000
Total Installed Cost	$19,490,000
Design, Construction Management Start-up (15% DCC)	2,924,000
Land (50,000/acre)	500,000
Legal Fees (3% DCC)	585,000
Bond Discount (3% Total)	705,000
Total Facility Cost	$24,204,000
Facility Cost Per tpd (Design Cap.)	$29,400

* 1 ton = 0.907 metric ton

TABLE 24. OPERATING COST--CO-INCINERATION/INDIRECT SLUDGE DRYER (Design Capacity: Refuse 600 tpd; Sludge 224 tpd)*

Item	Cost Per Ton *	Total Annual Cost
Manpower (46 employees)	$3.66	$ 753,600
Power (1265 kwh/hr)	1.20	247,700
Water/Sewer (485 gpm)	.32	65,900
Fuel (87,700 gpy)	.14	28,800
Maintenance (2.5% DCC)	2.36	487,200
Overheat (1% DCC)	.95	194,900
Residue Disposal (161 tpd)	.94	193,200
Total Operating Cost	$9.57	$1,971,300

*Based on throughput of:
Refuse -- 150,000 Tons Per Year
Sludge -- 56,000 Tons Per Year
Total -- 206,000 Tons Per Year
Divide by 0.907 to obtain cost per metric ton

TABLE 25. CONSTRUCTION COST--CO-INCINERATION/MULTIPLE HEARTH FURNACE (Design Capacity: Refuse 600 tpd; Sludge 224 tpd)*

Item	Cost
Shredder:	
Two Primary Shredders	$ 562,000
Two Screen & Mag. Separator	746,000
Two Secondary Shredder	628,000
Conveyors	930,000
SubTotal	$ 2,866,000
Pneumatic Conveying System (Shredder to Storage)	366,000
Storage Silo (166,000 cu ft)	1,541,000
Four Feed Conveyors (Storage to Furnace)	648,000
Four Multiple-Hearth Furnaces (22 ft diameter x 11 ft hearth)	13,800,000
Building	4,314,000
Direct Construction Cost	$23,535,000
Direct Construction Cost Per tpd (Design Cap.)	$28,600

* 1 ton = 0.907

TABLE 26. TOTAL FACILITY CAPITAL COST--CO-INCINERATION/MULTIPLE HEARTH FURNACE (Design Capacity: Refuse 600 tpd; Sludge 224 tpd)*

Item	Cost
Shredding Plant DCC	$ 5,421,000
Incinerator Plant DCC	18,114,000
Total Installed Cost	23,535,000
Design, Construction Management, Start-Up (15% DCC)	3,530,000
Land ($50,000/acre)	350,000
Legal Fees (3% DCC)	706,000
Bond Discount (3% Total Cost)	844,000
Total Facility Cost	$28,965,000
Facility Cost Per tpd (Design Cap.)	$35,200

* 1 ton = 0.907 metric ton

TABLE 27. OPERATING COST--CO-INCINERATION/MULTIPLE HEARTH FURNACE (Design Capacity: Refuse 600 tpd; Sludge 224 tpd)

Item	Cost Per Ton *	Total Annual Cost
Manpower (45 employees)	$ 3.40	$ 699,000
Power (2885 kwh/hr)	2.72	561,200
Water/Sewer (1310 gpm)	1.02	209,400
Auxiliary Fuel (85,300 gal/yr)	0.16	32,300
Maintenance (2.5% Incinerator DCC) (5% Shredder DCC)	3.20	660,000
Overhead (1% DCC)	1.14	235,400
Residue (161 Ton/day)	0.94	193,200
Total Operating Cost	$12.58	$2,591,100

* Based on throughput:
Refuse -- 150,000 Tons Per Year
Sludge -- 56,000 Tons Per Year
Total -- 206,000 Tons Per Year
Divide by 0.907 to obtain cost per metric ton

TABLE 28. CONSTRUCTION COST--CO-INCINERATION/PYROLYSIS (Design Capacity: Refuse 600 tpd; Sludge 224 tpd)*

Item	Cost
Two Shaft Furnaces	$18,125,000
Additional Building	1,541,000
Direct Construction Cost	$19,666,000
Direct Construction Cost (per tpd)	$23,900

* 1 ton = 0.907 metric ton

TABLE 29. TOTAL FACILITY CAPITAL COST--CO-INCINERATION/PYROLYSIS
(Design Capacity: Refuse 600 tpd; Sludge 224 tpd)*

Item	Cost
Pyrolysis Plant DCC	$19,666,000
Design, Construction Management Start-Up (15% DCC)	2,950,000
Land ($50,000/acre)	250,000
Legal Fees (3% DCC)	590,000
Bond Discount (3% Total Cost)	704,000
Total Facility Cost	$24,160,000
Facility Cost Per tpd (Design Cap.)	$29,300

* 1 ton = 0.907 metric ton

TABLE 30. OPERATING COST--CO-INCINERATION/PYROLYSIS
(Design Capacity: Refuse 600 tpd; Sludge 224 tpd)

Item	Cost Per Ton *	Total Annual Cost
Manpower (42 employees)	$ 3.15	$648,000
Power (1450 kwh/hr)	1.37	282,100
Water/Sewer (300 gpm)	0.23	48,000
Auxiliary Fuel & Heating (1,057, 400 gal/yr)	2.14	440,700
Maintenance (2.5% DCC)	2.37	491,600
Overhead (1% DCC)	.95	196,700
Residue (488 Ton/day)	0.71	146,500
Total Operating Cost	$10.92	$2,253,600

* Based on throughput:
Refuse -- 150,000 Tons Per Year
Sludge -- 56,000 Tons Per Year
Total -- 206,000 Tons Per Year
Divide by 0.907 to obtain cost per metric ton

TABLE 31. SUMMARY OF CO-INCINERATION COST ANALYSIS
(Basis:* Refuse 499 tpd; Sludge 187 tpd dry or wet; ENR 2246)

Item	Separate Incineration Refuse Incinerator	 M.H. Sludge Incinerator	Total	Rotary Drier	Co-Incineration Indirect Drier	 Multiple Hearth	Pyrolysis
Total Facility Cost	$19,100,000	$6,042,000	$25,142,000	$23,066,000	$24,204,000	$23,535,000	$24,160,000
Annualized Capital Cost	1,803,000	570,000	2,373,000	2,177,000	2,285,000	2,221,000	2,280,000
Annualized Capital Cost Per Ton+	12.01	10.18	11.52	10.57	11.09	10.78	11.07
Percentage Savings, based on Separate Incineration Total				8.2%	3.7%	6.4%	3.9%
Operating Cost	1,564,900	1,102,700	2,667,600	1,935,100	1,971,300	2,591,100	2,253,600 (1,222,600)**
Operating Cost Per Ton+	10.43	19.68	12.95	9.39	9.57	12.58	10.92 (5.93)
Percentage Savings, based on Separate Incineration Total				27.4%	26.1%	2.9%	15.5% (54.2%)
Total Annual Cost	3,368,000	1,673,000	5,041,000	4,112,000	4,256,000	4,812,000	4,534,000 (3,503,000)
Total Annual Cost Per Ton+	22.45	29.86	24.47	19.96	20.66	23.36	21.99 (17.00)
Percentage Savings, based on Separate Incineration Total				18.4%	15.6%	4.5%	10.0% (30%)
Total Annual Cost Per Ton+ (Based on Solids)	31.18	149.37	42.29	34.50	35.70	40.37	38.04

* Throughput Basis.
** Parenthesis denote credit for stream sale.
+ Divide by 0.907 for cost per metric ton.

Direct Operating Costs--

The direct operating cost of each of the four co-incineration techniques, like the capital cost, is less then the corresponding cost of separate incineration of sludge and refuse. Again, the magnitude of these cost differences will vary with the size of the incinerator. The percentage differences, as indicated on Table 31, can be expected to remain nearly constant.

Reductions in operating cost can be accounted for by cost savings in two major areas: manpower and auxiliary fuel. A total of 62 employees would be required for independent incineration, while co-incineration requires only 42 to 46 employees, depending on the process. The resulting savings approaches $300,000 per year, or $1.60 per metric ton ($1.45 per ton) of sludge and refuse processed. Auxiliary fuel, used primarily in the multiple-hearth sludge incinerator, also adds to the cost of the separate systems. With the exception of the pyrolysis plant, co-incineration should result in a fuel savings of about $450,000 per year, or $2.45 per metric ton ($2.22 per ton) of throughput. This corresponds to a savings of 4,500,000 liters (1,200,000 gallons) of fuel oil per year. The pyrolysis co-incineration technique requires a significant auxiliary fuel input; however, there is a definite potential for the sale of excess steam from this plant, with the corresponding benefit of recovery of energy and cost inputs.

Power costs do not have a major impact on cost differential, except in the case of multiple-hearth co-incineration. Here, power costs are high, because of the pressure drop in the venturi scrubbers and the power costs of operating the shredder plant.

Other factors making up the total annual operating cost (water/sewer service, maintenance, overhead, and residue disposal) do not have a major impact on the cost differentials between co-incineration and separate incineration of sludge and refuse.

Total Annual Cost--

Total annual cost, in total dollars or in dollars per ton, is the real indicator of cost differences between separate incineration and the four co-incineration techniques considered. Table 31 indicates the relative savings to be expected from co-incineration, as a percentage based on separate incineration costs. All co-incineration processes show a savings in total annual cost. The total cost savings is attained as the result of both capital and direct operating cost reductions associated with co-incineration.

At first glance, it is surprising to note that the cost-per-ton figures are lower for co-incineration than for typical refuse incineration. It would be indeed unusual to add complexity to the system and expect to reduce the processing cost. This anomaly can be accounted for by the water content in the sludge. Water adds significantly to the tonnage of material processed, although the water does not add to the actual loading on the incinerator. Table 31 also indicates co-incineration costs per ton of dry refuse and dry sludge. As expected, all co-incineration techniques are more costly than typical refuse incineration, on a strictly solids basis.

Comparison of the Selected Co-Incineration Techniques

Within the four co-incineration technqiues, there are definite cost differences. Direct rotary drying represents the lowest-cost option (assuming no steam recovery for pyrolysis), since it combines the lowest capital and operating cost of any of the systems. Indirect sludge drying follows closely, with slightly increased capital costs brought about by the required steam plant. Multiple-hearth co-incineration appears to be the least attractive alternative from an economic standpoint because of the high operating costs associated with the plant. Multiple-hearth co-incineration includes high power costs, high maintenance costs (mostly associated with the shredder plant), and high water and sewer costs (related to the venturi scrubbers on the furnaces).

With no credit for steam sales, pyrolysis falls between the pre-drying techniques and the multiple-hearth co-incineration technique in terms of processing cost. The high capital associated with this plant is partly offset by lower operating costs, resulting from reduced manpower requirements. However, pyrolysis has the potential for sale of the steam generated. If the steam credit is included, total processing costs could be reduced to about $19/metric ton ($17/ton), thus making pyrolysis the most economically attractive co-incineration process. However, since factors other than a steam market influence the plant location, revenue from steam sales cannot be assured with any co-incineration process. Therefore, a credit for steam sale should be taken only when it can be demonistrated that a market for the recovered energy is available within reasonable distances of the feasible co-incineration plant site.

Cost Trends

In considering cost alternatives for plants which will operate for 10 to 20 years, the effects of expected changes in cost parameters over the operating period should be considered. The basis for the capital and operating cost estimates in this Section is mid-1975. The major cost factors include capital, interest, manpower, fuel and power. Table 32 is a manpower and utility summary for the four co-incineration techniques.

Of course, it is impossible to predict cost increases for manpower and commodities with complete accuracy over a 10-year period. The figures presented below are little more than guesses, necessary to project operating costs in the future.

Capital and Construction--

There is little doubt that construction and material costs will continue to rise. However, after the plant is constructed, increases in capital costs will not affect the operating cost of the plant.

Increases in materials and construction costs will, however, affect maintenance costs. For the purpose of this study, we have projected maintenance costs at a constant rate. Actually, these costs will be lower for the first few years of operation, and then increase sharply as the plant ages.

TABLE 32. MANPOWER & UTILITY SUMMARY

	Separate Incineration				Co-Incineration		
	Refuse Incinerator	Sludge Incinerator	Total	Direct Dryer	Indirect Dryer	Multiple Hearth	Pyrolysis
Design Cap. (tpd)*	600	224	824	824	824	824	824
Throughput. (tpy)*	150,000	56,000	206,000	206,000	206,000	206,000	206,000
Employees	38	24	62	46	46	45	42
Power kwh/hr	845	150	995	1,265	1,265	2,885	1,450
Water/Sewer gpm**	420	275	695	435	485	1,310	300
Fuel, gallons per year**	18,400	1,238,400	1,256,800	128,800	87,700	85,300	1,057,400

* Divide by 0.907 to obtain metric tons per day (year).

** Multiply by 3.79 to obtain liters.

It is often advisable to set up a sinking fund during the early life of the plant, to offset higher maintenance costs in later stages of operation. On this basis, increases caused by inflation can be largely offset.

Personnel--

Manpower costs can also be expected to continue their upward spiral into the foreseeable future. Manpower costs will continue to escalate, for reasons common to the rest of the economy and as a result of the organizational support from municipal employees' unions. On the average, we have projected an increase of 7 percent per year, thus almost doubling the cost of wages, salaries, and fringe benefits over the next 10 years.

Power--

Power costs can also be expected to increase over the next few years; however, the impact of nuclear power plants expected on-stream within the next decade will partially offset increases in fossil fuel costs. Also, the fact that incinerators pull a relatively steady load, rather than a sharply peaked load, will maintain power costs on the low side of the rate schedule. The substitution of coal for imported oil should also hold down the cost of power generation. In ten years, we have projected a power cost increase from 2.7¢ to 5¢ per kilowatt-hour (6.4 percent increase per year).

Fuel--

The cost of fossil fuel is certain to rise as reserves dwindle. Unfortunately, auxiliary fuels necessary for incineration and co-incineration must be petroleum-based products, and there is little opportunity for substitution of coal for oil or gas in this application. In the absence of major increases in fuel oil reserves within the United States, fuel oil costs will continue to be controlled by exporting nations.

Increases in fuel costs will be checked, however, by reduced demand, substitution of nuclear and third-generation power sources, and the impact of unchecked fuel costs on the world economy. We have therefore projected an increase in fuel oil costs to approximately $0.16/liter ($0.60/gal) during the next ten years (4.7 percent increase per year).

Water and Sewer Service--

Water and sewer costs should not be a major factor in co-incineration costs, because the incinerator would be located at or very near a water-treatment plant, and there should be ample supplies of process cooling water, at a continued low cost.

Residue Disposal--

The cost estimate has assumed off-site residue disposal by private contractor. With effective incineration, residue should be minimized, and the actual cost of disposal is not expected to increase sharply. If it does, municipally owned and operated landfills can supplant private operations, thus maintaining control over residue disposal cost.

Resource Recovery--

On the positive side, new techniques and markets for recovered resources are expected to reduce refuse processing costs. At present market conditions, costs could be reduced by as much as one dollar per ton by simple magnetic separation and sale of ferrous metals. As naturally occurring raw materials are consumed, and are supplanted by recovered and recycled materials, other components may find new markets. Table 33 lists 1985 projected processing costs, based on the inflation factors listed above. There are several significant conclusions to be drawn from these data:

1. The sensitivity to inflation for all co-incineration techniques is approximately the same. Pyrolysis, with steam revenue included, has the smallest increase in operating cost for the 10-year period.

2. Separate incineration of sludge and refuse is highly susceptible to inflation, because of the cost contribution of the sludge incinerator. Both fuel and manpower costs contribute heavily to the increases projected for sludge incineration costs.

3. Cost savings expected from co-incineration processes will be greater in 1985 than at today's costs. Both the actual dollar amount and the percentage of expected savings will increase as inflation raises the cost of separate incineration of sludge and refuse at rates faster than for co-incineration.

4. Inflation does not appreciably affect the relative ranking of the various co-incineration techniques. Thus, a choice of system based on 1975 economics should remain economically sound in future years.

Table 33. 1985 CO-INCINERATION COST ANALYSIS

Item	Separate Incineration			Co-Incineration			
	Incineration	M.H. Sludge Incin.	Combined	Rotary Dryer	Indirect Dryer	Multiple Hearth	Pyrolysis
Operating Cost, $							
Manpower	1,229,000	746,000	1,975,000	1,464,000	1,482,000	1,376,000	1,275,000
Power	304,000	54,000	358,000	459,000	459,000	1,039,000	522,000
Water/Sewer	55,000	44,000	99,000	60,000	66,000	209,000	48,000
Fuel	9,000	753,000	762,000	65,000	46,000	51,000	698,000
Maintenance	382,000	115,000	497,000	464,000	487,000	660,000	492,000
Overhead	153,000	46,000	199,000	186,000	195,000	235,000	197,000
Residue Disposal	180,000	13,000	193,000	193,000	193,000	193,000	146,000
Total OOP Cost, $	2,312,000	1,771,000	4,083,000	2,891,000	2,928,000	3,763,000	3,408,000
Debt Service, $	1,803,000	570,000	2,737,000	2,177,000	2,285,000	2,221,000	2,280,000
Total Annual Cost, $	4,115,000	2,341,000	6,820,000	5,063,000	5,213,000	5,984,000	5,688,000(4,211,000)[*]
1985 Cost Per Ton Of Throughput[+]	27.43	41.80	33.11	24.60	25.30	29.05	27.61 (20.44)
1975 Cost Per Ton Of Throughput[+]	22.45	29.80	24.47	19.96	20.66	23.36	21.99 (17.00)
% Increase	22.2%	40.3%	35.3%	23.3%	22.4%	24.4%	25.6% (20.2%)
% Saving Based On Separate Incineration				25.7%	23.6%	12.3%	16.6% (38.3%)

[*] Parentheses denote credit for steam sale.
[+] Divide by 0.907 for cost per metric ton.

SECTION VIII

CIRCUMSTANCES HAVING IMPACT ON FEASIBILITY

Although the technical and economic feasibility of co-incineration systems is a basic consideration, there are circumstances, events, and situations of a less quantifiable type that can affect the desirability or practicality of implementation:

- Geography
- Local Political Situations
- Cooperation between Public Agencies
- Public- and Private-Sector Factors
- Government Funding
- Relative Acuteness of MSS or MMR Disposal Problems
- Local Cost Factors
- Auxiliary Fuels

The following discussions present our qualitative judgments on the impact of these factors on this implementation of co-incineration in the United States.

"All generalizations, this one included, are no damn good" (Oliver Wendell Holmes). This quotation is presented not as an escape from responsibility for the subjective judgments given, but rather to counsel the reader to recognize that local conditions can cause or prevent actions -- even in the face of "national trends."

GEOGRAPHY

A 1970 EPA study of the air pollution impact of municipal incineration ("Systems Study of Air Pollution from Municipal Incineration," NAPCA Contract CPA-22-69-23, by W.R. Niessen et al.) showed that both population and population density were significant variables in correlating the incidence of refuse incinerator construction with local conditions. Further investigation of the relative impact of these two factors resulted in the derivation of the following expression:

$$y = a(P \times P/A)^2 + bP$$

where y is the incidence of incinerator construction

P is population

P/A is population density

Comparison of predicted and actual values produced a correlation coefficient squared of 0.8. This correlation indicates incinerators (reflecting solid waste disposal problems so severe as to justify costly volume-reduction problems) will be constructed where large waste loads (population) and intensive land use (high population density) occur together. An equally plausible speculation would equate great economic resources and technical sophistication to State Economic Areas having large populations. Although no such analysis for correlating the installation of incinerators for wastewater sludge disposal is available at this time, it appears reasonable to conclude that similar coincident forces would result in installation of sludge incinerators. This suggests that co-incineration can be expected to take hold most quickly in the major metropolitan areas in southern New England, Delaware, New Jersey, New York, Pennsylvania (Region II); Maryland, Florida, Michigan, Hawaii, and Wisconsin.

A second geographical factor is the degree of correlation and coincidence between the jurisdictions responsible for solid waste and those responsible for sewage treatment. In general, solid waste jurisdictions closely, sometimes fiercely, follow political boundaries. Sewage treatment systems may follow political boundaries, but they also reflect the hydrological basins conducive to gravity flow. Clearly, a congruence of responsibility will encourage co-incineration, because:

1. A common administrative structure and, often, a common cost distribution system will obtain.
2. Any economic and/or environmental benefits of joint disposal of MSS and MMR will more clearly support the collective good.
3. Problems in MSS disposal will be felt by those with MMR responsibility and vice versa. Thus, seeking after advantageous joint approaches to resolving the problem will be more obvious and plausible.

Another point relating to geographical impact arises from the following:

1. Sewage treatment plants (STP) are usually located next to receiving streams in low-lying areas, which are often poor locations for a landfill.
2. For a number of reasons (hauling cost, odor in hauling and storage), the co-incineration plant should be located adjacent to the STP.
3. For economy, in both work force and transportation expense, it is desirable to locate the residue disposal site adjacent to the incinerator.

Thus, co-incineration tends to penalize the MMR disposal function.

LOCAL POLITICAL SITUATIONS

Because of the frequent mismatch of jurisdictions responsible for MMR disposal and for MSS disposal, it is almost a foregone conclusion that co-incineration will require interjurisdictional cooperation. Particularly in the more independent rural states and regions, such cooperation is viewed with suspicion and open hostility. More than one political figure has been defeated at the polls because he was "soft" on independence. Although such an adverse situation does not hold in all areas of the country, the repeated failures or, at least, the ponderously slow pace of even regional STP construction is testimony to its impact. Furthermore, co-incineration is capital-intensive and thus (when landfill is a viable alternative for either MMR or MSS disposal) will be politically unattractive, especially in hard economic times.

On the positive side, co-incineration may be viewed as "modern," incorporating conservation of materials and energy resources. Such positive features will be useful for political posturing, but, most likely, would not produce a firm commitment to the concept unless the electorate were unusually enlightened.

On balance, political realities will probably have a net negative impact on the implementation rate of co-incineration systems.

COOPERATION BETWEEN PUBLIC AGENCIES

In many jurisdictions, the STP agency is organizationally distinct from the solid waste agency. The former is often an Authority or other regional organization, whereas the solid waste activity is usually tied closely to jurisdictions headed by elected officials.

These generalizations are, clearly, more valid when the seat of political power is at the state and municipal levels rather than at the county level. With a strong county government, a STP district and a solid waste organization to match it are often both under a central control, and, importantly, the citizens look to a single seat of authority to solve both solids disposal problems. When this is not the case, or whenever the control or prestige of elected officials would be perceived to be weakened by joint action, one can anticipate foot-dragging and "poor cooperation."

The incentive needed for cooperation, and for a resolution of the political "costs" previously discussed, may be to identify and publicize a clear-cut benefit, or at least a lesser cost, associated with a cooperative effort. Such benefits may be found if the public is well-enough informed to make non-support of co-incineration totally unacceptable. Except in rare instances, however, it is difficult to achieve such a state of public awareness. More reasonable to expect is the use, by the enlightened official, of a "new landfill crisis" to tout the benefits of a solution not requiring landfill. Nevertheless, the official may have to accept some erosion of his power base to accomplish these goals. Not all are willing to do this.

In summary, needed interagency cooperation can be expected if those responsible for MMR and MSS both report to a powerful central elected official. If the senior officials differ, one or the other, or both, will probably fail to exhibit a strong cooperative spirit.

PUBLIC- AND PRIVATE-SECTOR FACTORS

In almost all areas, sewage treatment is provided by public agencies (local, regional, and state). In contrast, many solid waste collection and disposal services are provided by the private sector, and control of these private-sector activities is usually limited to environmental protection regulations and zoning control of land use. Generally, refuse collection and disposal is a very profitable business. The refuse disposal industry is particularly powerful, both politically and economically, in the urbanized regions -- the same regions where co-incineration generally is both needed and economical. It is reasonable to expect, therefore, that wherever the solid waste industry is strong and is deeply involved in solid waste disposal the industry will exercise its influence to stop, or at least slow the implementation of co-incineration.

Where the private sector is involved in collection but not in disposal, its receptiveness to co-incineration will largely relate to the degree that the hauling time is affected. If, as indicated in the discussion of geographical factors, the STP/co-incinerator facility is located at some distance from, say, present landfills, the resultant refuse collection dis-economy will lead to counterpressure from this group. This situation will be particularly true if competing firms can make use of more strategically located disposal sites. Conceptually, such competitive stresses could be balanced by the disposal fee structure and by exercising control over dumping sites, but such procedures would undoubtedly be complex and/or legally delicate.

A measure of support from segments of the private sector may be obtained if co-incineration systems are constructed and/or operated under turnkey or full-service contracts. Such direct participation will be limited in its influence, however, and, on balance, the influence of private-sector involvement in solid waste will have, at best, a null impact and, more likely, will tend to repress co-incineration.

GOVERNMENT FUNDING

Government funds exert a profound influence over the direction and degree of capital investment by public bodies. The availability of federal planning grants often determines the patterns of future development. The federal grant program, as presently constituted, directly affects co-incineration, because:

- Most early solid waste planning grants were oriented to the development of state-wide plans. Regional planning was later encouraged, but funds were cut off before sufficient momentum was attained. Present efforts in many states are still state- or county-oriented.

- Most sewage and sewage treatment planning has been carried out regionally, with river basins or other natural drainage boundaries defining the region and, in time, the sewage service districts.

- Federal construction grants have been closely limited to wastewater collection and treatment systems, partly through strict interpretation of legislation and partly through a lack of interest and a lack of technical expertise in the needs, disciplines, and problems of non-water media.

At the present time, several major national situations are emerging:

1. Increasing shifts to treatment equivalent to secondary or better treatment will make MSS disposal a major problem by 1980.

2. Increasingly stringent land disposal requirements (for ground-water protection) will increase the difficulty of finding and constructing landfill disposal sites for MSS. With ocean barging in disfavor and land spreading an environmental question mark, sludge incineration may become the preferred or the only acceptable alternative.

3. Auxiliary fuel for sludge incineration is increasingly costly, difficult to obtain, and may represent an inferior use to an emerging national energy policy which emphasizes conservation.

4. MMR landfills, as for MSS, are becoming harder to find and more costly to operate.

5. Resource recovery, as it is practiced in many co-incineration technologies, responds to a growing national desire for conservation.

Therefore, if the results of this project and other investigative efforts indicate that co-incineration should play a major role in mitigating the MSS/MMR disposal problems and in meeting their challenges, a shift in Federal planning and construction grant policy could be extremely conducive to the rapid, probably pervasive introduction of co-incineration as the way to go.

RELATIVE ACUTENESS OF MSS OR MMR DISPOSAL PROBLEMS

Conceptually, a problem with MSS or MMR disposal will, at a minimum, encourage looking at co-incineration. More likely, however, an MMR problem will not lead to an investigation of co-incineration unless an MSS disposal crisis also exists or is clearly forecast. In contrast, an MSS problem leads to consideration of incineration, and the projected high fuel costs for MSS incineration practically demand evaluation of co-incineration. Our judgment, therefore, realizing the increasing enormity of the MSS disposal problem, is that the co-incineration option will receive more attention in the future.

Running counter to this forecasted enthusiasm by those with MSS disposal problems is the rapidly growing interest in the use of prepared refuse as a utility boiler fuel or as the feed to a refuse boiler-incinerator which markets steam. The lower apparent technical risk of the MMR-based energy recovery approach, the absence of a requirement for interjurisdictional cooperation, and the political attractiveness of energy recovery make for a powerful competitor for co-incineration, even if the net effect is a not-so-favorable jurisdictional energy use pattern.

LOCAL COST FACTORS

Co-incineration is a high-capital-cost, high-operating-cost disposal method for either MMR or MSS when compared with landfill. To the extent that there are alternatives, therefore, areas with a high construction cost index and with powerful public-servant unions will find co-incineration unattractive. Unfortunately, the same geographical factors which might appear to stimulate co-incineration often are paralleled with these economic disincentives. Another view is that if co-incineration must come its introduction will place unusually heavy burdens on those with the fewest alternatives.

AUXILIARY FUELS

As mentioned in the preceding discussions and as recommended in recent EPA reports, incineration, using auxiliary fuels, may become the preferred method for MSS disposal. The fuels typically used as auxiliaries include gas and light fuel oil, both of which are in short supply and have rapidly escalated in cost.

If no major fuel supply crisis (such as the oil boycott of 1974) occurs again, it is reasonable to assume that such fuels could be reliably obtained for MSS disposal, though at a high price. Given the emergence of co-incineration as a viable technical alternative, if the cost of refuse-energy preparation and other costs ascribable to co-firing are competitive, co-incineration should take hold as the preferred alternative. This basic economic decision would probably be made, albeit more slowly, without the changes in Federal grant policy indicated above. With such changes, however, and with further encouragement by the Federal energy-related agencies, co-incineration should be expected to achieve dominance rather quickly, particularly on the eastern seaboard.

APPENDIX A

ANNOTATED BIBLIOGRAPHY

Reference: Albrecht, O.E. Schlammverbrennung im Wirbelschichtofen (Sludge Incineration in Fluidized Bed Furnaces). Chemie Ing. Techn. 41,10:615-619. May 1969.

Abstract: The fluid bed sludge incinerator in Lausanne, Switzerland was operational in 1965 and has a capacity of 2,600 kg (5,700 lb) filtercake/hour, with a peak of 3,120 kg (6,860 lb) having a maximum water content of 60 percent. The sludge is fed by gravity through a pipe that penetrates the reactor head into the furnace freeboard. Besides sludge, it was possible to incinerate other waste materials, such as oils, coal dust, saw dust, clay, coffee, sludge, soot, fruit peel, etc. Even refuse incineration experiences were positive. Although large amounts of solid wood, bottles, slaughter house waste, and other refuse were incinerated without previous crushing, good combustion was obtained.

Reference: Anderson, J.D. Solid Refuse Disposal Process and Apparatus. U.S. Patent Number 3,729,298, dated April 24, 1973.

Abstract: The patent is assigned to Union Carbide Corporation and covers the oxygen-blown shaft furnace marketed under the tradename of "Purox System." The inventor discusses the impact of oxygen-enriched combustion air on the combustion temperature, on the air pollution control equipment, and on the heating value of the pyrolysis off-gas. There are 25 claims, and STP sludge is specifically mentioned in the disclosure as disposable along with MMR.

Reference: Anon., Incineration Gobbles up Plant Wastes. Chemical Engineering, Pages 50-52, October 5, 1959.

Abstract: Dow Chemical Company's industrial solid wastes (including drums), high- and low-Btu liquid wastes are burned in a 4 m (13') diameter by 11 m (35') long rotary kiln incinerator. Combustion is completed in a stationary secondary combustion chamber. The high-Btu liquid wastes are concurrently fired to insure burnout of the largely plastic solid wastes and low-Btu liquids. Refuse provides slag and ash that aids the combustion of the plastics and liquid chemicals.

Reference: Anon., Sewage Sludge Drying. Bartlett-Snow-Pacific, Inc. Engineering Bulletin No. SE-2, April 1, 1966.

Abstract: At Holyoke, Massachusetts, primary sludge is dewatered in vacuum filters (with ferric chloride and lime conditioning) to 25-35 percent solids. Filter cake is mixed with dried sludge in a pug mill and fed to a rotary dryer.

Flue gases from the MMR incinerator dry the sludge, and the spent gases discharge to the MMR expansion chamber. The dried sludge is screw-conveyed to the MMR furnace. The dryer can also be fired by #4 fuel oil when necessary. The system was operational in May of 1965.

This Bulletin states, "the dryer was necessary because undried sludge ... depressed the temperature of the incinerator burning zone too much for proper operation." The pug mill is also used to prevent "wet cake from forming large balls in the dryer."

Reference: Anon., Fluid Bed Incinerators Studied for Solid Waste Disposal. Environmental Science and Technology 2,7:495-497, July 1968.

Abstract: This article generally reviews the use of fluid-bed incinerators for disposal of solid refuse. Fluid-bed incinerators offer the following advantages over conventional grate incinerators: rapid and complete combustion, minimum excess air (5 percent vs. 250 percent for grate incinerators), smaller stack-gas cleaning equipment, low concentrations of unburned hydrocarbons and oxides of nitrogen, large heat sink, compactness, and possible waste heat recovery (as much as 50 percent of the heating value of the refuse).

During pilot-plant work at West Virginia University, two problem areas were encountered. Feed of raw solid waste to the incinerator presented some difficulties, probably because of the small scale of the unit. The largest problem seems to be removal of residue from the fluidized bed.

Reference: Anon., Kehrict- und Schlammverbrennungsanlage Region Dübendorf (Incinerator Plant for Domestic Refuse and Sewer Sludge in the Dubendorf Area). Schweizerische Zeitschrift für Hydrologie 31, 2, 1969. (Presented at the Fourth Internation IAM - Congress, 1969, in Basel, Switzerland, 1969.)

Abstract: The Dübendorf, Switzerland incineration plant is situated on the property of the sewage purification plant. It has been designed for incineration of domestic refuse and liquid raw sludge. After treatment in a grinder, the refuse is mixed with the liquid sludge and the mixture in then incinerated in a multiple-hearth furnace. Refuse which cannot be ground is burned in an auxiliary furnace, and the flue gas resulting from this operation is then burned in the main furnace. The heat resulting from incineration of the refuse is utilized for combustion of the liquid sludge in the same furnace. A wet process is applied for flue gas purification.

Reference: Anon., Solid Waste Disposal. Chemical Engineering, Pages 155-159, June 21, 1971.

Abstract: The only reference to co-incineration is the following:

> A pyrolytic system for the joint handling of sludge and municipal refuse was recently put into operation in South Houston, Texas. The $600,000 system, designed by Waste Control Systems, Inc., an affiliate of Houston Natural Gas Corp., is capable of handling 100 tons/week. The sludge is pumped from a tertiary treatment plant to a concentrator

for dewatering. It is then discharged directly into the pyrolysis plant. A small tractor is used to push the trash and sludge alternately into the loading devices.

Waste Control Systems, Inc. (a division of Houston Natural Gas), a maker of rotary incinerators, supplied the unit for South Houston. It was intended to burn "nearly dry" sludge, not raw sludge. The incinerator can be equipped with a screw charger for heavier materials such as sludge, and uses waste-heat recovery to pre-heat incoming combustion air.

Waste Control Systems, Inc. knows of no one co-incinerating refuse and sludge in any of its equipment.

Reference: Anon., The Reigate incinerator. Surveyor (London) 138, 130:34-35, August 6, 1971.

Abstract: In this furnace, which was operational by the end of 1972, the top hearths are used for drying the sludge, which is introduced to the top hearth. The shredded refuse is introduced to an intermediate hearth, and the lowest hearths are used for ash cooling and combustion air preheating. There are four sludge-drying hearths, two refuse-combustion hearths, and two cooling hearths.

The raw sludge contains 6 to 7 percent solids; no further data are provided. The article states that oil is used for start-up, and that the combined process is autogenous thereafter. The refuse is shredded, and magnetically separated solids are rejected from the system. Any bulky oversize pieces that cannot be passed through the pulverizer are placed in an auxiliary furnace, the exhaust from which goes to the multiple-hearth furnace. The shredded refuse is charged by a grapple to a conveyor and is fed via chute to an intermediate hearth on the multiple-hearth furnace. Hot air is also introduced from a combustor, which is apparently used for start-up only.

Reference: Anon., A 12-Year Record of Achievement in Pollution Control. Copeland Systems, Inc., Brochure No. CS-14.

Abstract: The Thunder Bay installation features fluidized-bed incineration of pulp mill wood and bark wastes, capacity 150 metric tons (170 tons) per day, bone-dry basis. It is located in Thunder Bay, Ontario; The Great Lakes Paper Company Ltd. scheduled it to start up in 1971.

Designed Feed Rate--Normal Operation

1. Ground wood & sulfite mill sludges @ 25% solids, tpd, bone-dry basis . . .	40
2. Kraft mill sludge @ 25% solids, tpd, bone-dry basis	5
3. Ground wood rejects @ 25% solids, tpd, bone-dry basis	5

4. Kraft Mill rejects @ 25% solids, tpd, bone-dry basis	5
5. Waste wood debris @ 40% solids, tpd, bone-dry basis	50
6. Surplus bark @ 35% solids, tpd, bone-dry basis	20
Total, tpd.	120

The Manistique Pulp and Paper Co., Manistique, Michigan installation also uses fluidized-bed incineration of waste wood and sludge, capacity 27 metric tons (30 tons) day. The unit was scheduled to start up in 1972:

Design Conditons

1. Feed rate, tpd	30
2. Feed solids, %	30
3. Combustion temperature, °F	1,350-1,500

Reference: Anon., Krefelder Müllverbrennungsanlage mit Klärschlammbeseitigung an VKW/BSH vergeben (VKW/BSH Granted Contact to Build an Incinerator for Refuse and Sewage Sludge at Krefeld). Staetehygiene 23, 8:4, August 1972.

Abstract: A new incineration plant is to be constructed in Krefeld, Germany, initially with two units with a throughput of 12 tons/hour. A third unit of the same capacity is scheduled for installation at a later date. Sewage sludge will be incinerated, together with refuse. The sludge will be dewatered in centrifuges, preheated with flue gases from the furnace, milled, and blown into the main combustion zone. This will provide complete combustion of the sludge. The heat will be used for the generation of steam and electricity. An electrostatic precipitator and a stack 150 m (490 ft) high guarantee the maintenance of the required emission standards. The plant was scheduled to be in operation by the end of 1974.

Reference: Anon., Twin Cities to Have Pyrolysis Plant. Public Works Page 56, October 1973.

Abstract: A plant will be built (1980) in the Twin Cities (Minneapolis-St. Paul, Minnesota) to dispose of 1,100,000 cu m/day (290 mgd) of sludge and 360 metric ton/day (400 tpd) of refuse by pyrolysis. The useful gas by-products will be used as fuel and will be sufficient for the complex when run on full-scale operation. Other by-products will include ferrous and other metals, fertilizer, and organic chemicals.

Reference: Anon., Refuse Refineries--A Danish Development. Environmental Pollution Management 4,4:183-185, July/August 1974.

Abstract: Shredded, cleansed refuse is decomposed in indirectly heated, closed, vertical retorts at 800-1,000°C (1,500-1,800°F). The alkaline portion of the refuse reacts with the acid gases, and the pH of the stack gas condensate is 8.5. Liquid wastes can be added to the refuse, but in the prototype plant in Kalundborg the plans called for simply drying sewage sludge. The solid waste pyrolysis portion of the system was operation in 1971 and the sludge drying system in 1972.

Reference: Anon., Solid Waste and Sludge--Energy Self-Sufficiency. Resource Recovery and Energy Review 2,1:16-17, January/February 1975.

Abstract: Central Costa County, California plans to co-incinerate MMR and MSS in multiple-hearth furnaces. Ferrous metal and aluminum will be removed from the MMR and the combustible fraction will be burned. The MSS will be dewatered by a two-stage centrifuge operation.

Tests were run in November of 1974 at Envirotech's Brisbane, California Test facility. During these tests, the sludge (primary plus secondary) was dewatered with some of the refuse and fed to the second hearth on an eleven-hearth furnace; the balance of the refuse was fed to hearths six and eight. The furnace was operated under reducing conditions to provide pyrolysis gases to the after-burner, which raises off-gas temperatures from 430 to 760°C (800 to 1,400°F) to assure complete oxidation of residual wastes. The advantages of the hybrid system are said to be:

1. The wastewater treatment plant and the solids recource-recovery facility would be energy self-sufficient in an era of rising energy prices.

2. There is a direct correlation between wastewater and solid waste generation. Hence, an adequate future supply of solid waste would be assured.

3. The integral facility would not be dependent on an outside market and pricing structure, as is the case with a separate resource-recovery plant producing electrical power or prepared fuels.

4. As a combined facility, the solid waste resource-recovery portion appears eligible in all or part for construction grant funding from EPA and some State sources.

In addition to co-incineration plans, there are plans to incorporate waste-heat boilers to power steam turbine-driven aeration blowers and electrical generators. The balance of the steam produced would be used for plant heating and air conditioning purposes.

Reference: Bayon, E.J. Sludge-disposal Solution: Thicken, Filter, Dry and Burn. The American City. June 1966.

Abstract: At Holyoke, Massachusetts, sludge (dewatered in vacuum filters) is dried in an insulated rotary sludge dryer 2.1 m (7 ft) in diameter and 12 m (40 ft) long. The dryer uses hot gases from an adjacent 200 metric ton/day (225 tpd) refuse incinerator to dry the sludge from 70 percent to 20 percent moisture content before the dried sludge is burned in the refuse incinerator.

The dried sludge is blown into the incinerator by air jets. The hot gases from the refuse incinerator are tempered with ambient air to 650°C (1,200°F) before entering the dryer, and the dryer-vent gases, at 150°C (300°F), are returned to the incinerator system expansion chamber. One-fourth of the sludge from the dryer is recycled and mixed with dewatered sludge in a pug mill before feeding the rotary dryer. The dryer is equipped with an auxiliary oil burner that is used to supplement or replace the hot incinerator gases when necessary.

Reference: Bergling, S. Combined Treatment of Refuse, Sewage Sludge, Waste Oil and Nightsoil at Luleå, Sweden. International Solid Wastes and Public Cleansing Association (ISWA) Information Bulletin No. 1, pages 25-28, September 1969.

Abstract: There are two furnace systems at Luleå, Sweden, each consisting of a 330 metric ton/day (360 tpd) refuse incinerator and a 2.4-meter by 16-meter (8' x 52') rotary dryer/incinerator capable of handling 15 cu m (530 cu ft) per hour of thickened sludge. Flue gases from the refuse furnace can be passed through the rotary drum, which is also equipped with waste oil burners. The gases from the rotary drum discharge into the refuse furnace flue upstream of the wet washer air pollution control device. The sludge can be dried or incinerated, but most of the sludge has been incinerated. Odor problems have been encountered, and waste oil quantities have exceeded projections. The system was reportedly operational before 1969.

Reference: Burgess, J.V. Developments in Sludge and Waste Incineration. Process Biochemistry 8,1:27-28, January 1973.

Abstract: The following is quoted from the paper, concerning "combined incineration":

> Whatever methods are used for sludge dewatering and conditioning, the operation is still a costly part of the disposal process. Removal of capillary water can be done by thermal means, and if a source of inexpensive heat is available, then this can be carried out within the multiple-hearth furnace. This has led to the development of simultaneous or combined incineration of high calorific value wastes and sludge. Many examples of this can now be seen. The Lurgi-Ebingen process combines the incineration of refuse and sludge in a single multiple-hearth furnace. In this process household refuse or industrial waste is conveyed directly to the combustion hearth of the furnace. Liquid sludge with a water content of 93-95 percent is pumped directly to the top of the furnace and as the sludge passes through the drying zone, water is evaporated, the heat being provided by the excess heat from burning of the combustibles in the solid waste. Waste oils or other organic liquids can be fed direct to the combustion zone. Many notable examples of this process may now be seen in Europe. Figure 1 [photograph of plant exterior] shows the installation now being completed at Reigate which is capable of burning 4-8 t/hr of sewage sludge and 3-7 t/hr of domestic refuse. A separate furnace for bulky wastes is provided, the waste gases from this furnace being fed to combustion zone of the main furnace. The economics of this process are remarkably attractive if there is a convenient source of solid waste requiring disposal.

The Lurgi-Dordrecht process of combined waste incineration permits simultaneous incineration in a separate furnace. With this arrangement, the hot waste gases normally leave the solid waste furnace at about 1,000°C and pass directly to the combustion zone of the multiple-hearth (MH) furnace. Again, the liquid sludge is fed direct to the top of the MH furnace and in a similar way to the Ebingen process, the heat from the refuse passes upwards in the MH furnace, drying the sludge moving downwards in countercurrent manner. At Dordrecht, a plant of this type is now working and will ultimately burn 21 t/hr of refuse and 21 t/hr of sewage sludge. The process has been used with equal success for industrial wastes, and an installation at a large chemical works successfully incinerates 1-3 t/hr of biological sludges in combination with 0-5 t/hr of factory waste.

Reference: Cardinal, T.J., Jr. and F.P. Sebastian. Operation, Control and Ambient Air Quality Considerations in Modern Multiple Hearth Incinerators. Proceedings and Discussions of ASME National Incinerator Conference, 1972.

Abstract: The authors argue that multiple-hearth sludge incinerators are not a source of odor (because there is a thermal jump that occurs before odor evolution and where the sludge to be burned goes from a damp to an ignition state almost instantaneously).

> Further investigation has proved that the sludge cake readily ignites in a multiple hearth furnace when the moisture content has been reduced to approximately 48 percent, thus, staying within the researched ranges. It is not uncommon, in fact, to see sludge burning vigorously in the middle of a hearth, and, immediately adjacent to the hot coals, filter cake from which steam vapor is being evaporated. The average temperature of this zone would be 1,400°F.

The authors further comment on a proposal that, for the destruction of insecticides and polychlorinated biphenyls, EPA may mandate that all incinerators operate with an exhaust gas temperature of 870°C (1,600°F) and with a residence time of two seconds. They state, "This requirement can be achieved through the multiple hearth unit by feeding sludge to the second or third hearths of the unit and altering the furnace temperature profile and excess air distribution." The paper further contains considerable information on cost of operation and maintenance and on aspects of air pollution impact.

Reference: Chapman, R.A. and F.R. Wocasek. CPU-400 Solid-Waste-Fired Gas Turbine Development. Proceedings of ASME National Incinerator Conference, 1974.

Abstract: The authors discuss the combustion of shredded, cleaned, municipal refuse in a fluid-bed furnace and propose that sludge be disposed of along with the municipal refuse. "The capacity of each power module would be significantly increased by using water or sewage sludge instead of excess air to keep system temperatures below the maximum allowed turbine inlet temperature. A Solar Centaur turbine is estimated to be capable of consuming 160 tons/day of solid waste and 44,000 gallons (167,000 l) of water or undewatered sewage sludge at 100 percent excess air while generating 3 mw of power....Sludge disposal incomes are site sensitive, and must be evaluated on an individual basis...."

Reference: Clinton, M.O. Experience with Incineration of Industrial Waste and Sewage Sludge Cake with Municipal Refuse. Proceedings of the 14th Purdue Industrial Waste Conference, Pages 155-170 (1959).

Abstract: The Neenah-Menasha incinerator plant (operational: April 1958) consists of two Combustion Engineering traveling-grate furnaces. The design capacity of the plant is 140 metric ton (150 tons) per day. The sewage from the treatment plant is vacuum-filtered to a 70 percent moisture content. The cake is then dried in a flash dryer (Combustion Engineering Raymond flash drying system) to a 15-20 percent moisture content. It is then separated in a cyclone and conveyed to the furnace by a belt conveyor and apparently added to the refuse at the furnace feed hopper. The feed to the furnace is reported to be: 27 metric ton/day (30 tpd) garbage (80 percent moisture); 76 metric ton/day (84 tpd) rubbish (10 percent moisture); and 32 metric ton/day (35 tpd) sludge (15-20 percent moisture). The gases from the drying circuit are discharged to the breeching before the stack. The hot gases are apparently drawn from the residue end of the furnaces.

It is reported that the refuse and sludge solids are rich (high heating value) but that the incinerator will be shut down because of age and the expense involved in meeting current air pollution control regulations. The plant has had maintenance problems and uncontrolled combustion because of variation in the characteristics of the refuse.

The Kewaskum incinerator (operational: October, 1954) consists of a Nichols furnace with a capacity of 23 metric ton/day (25 tpd) (batch-feed presumed). The primary and secondary sludge is dewatered using a vacuum filter, and the dewatered sludge is added to the raw refuse before charging the furnace. It is reported that the plant stopped burning sludge in the furnace after a while, because of insufficient heat supplied by the refuse.

Reference: Cross, F.L., Jr. R.J. Drago, and H.E. Francis. Metal and Particulate Emissions from Incinerators Burning Sewage Sludge and Mixed Refuse. Proceedings and discussions of ASME 1970 National Incinerator Conference, pages 189-195, May 1970.

Abstract: At the Waterbury, Connecticut plant--two batch-fed MMR furnaces of 140 metric ton/day (150 tpd) capacity each--tests were conducted to determine the metal and particulate emissions while burning sewage sludge and refuse together (1:3.5 Ratio), and while burning refuse only. It was found that emissions from sludge and refuse burning were 1.7 times greater than those when burning refuse only.

The sludge is dried in a Raymond Flash Dryer system and burned in suspension in the refuse furnace. The APC device is a wetted impingement baffle, and "the sludge burned is a unique sludge from a highly industrialized area with a large portion of the industry being metal industry (copper and others)."

Reference: Davies, G. Altrincham Refuse and Sewage Sludge Incineration Plant. Public Cleansing 63,5:247-256, May 1973.

Abstract: The 200 metric ton/day (220 tpd) Altrincham incinerator plant in England (operation in November 1972) consists of two continuous-feed, stoker-fired, refractory-wall furnaces complete with evaporative gas-conditioning systems and electrostatic precipitators (ESP's). The furnace is ram-fed, and the stoker is a two-section Heenan Nichols rocking-grate unit. The raw sludge at 5 percent solids is sprayed into each furnace through the end walls.

The incinerator plant processes the domestic, commercial, and industrial refuse from five participating authorities, but sludge from only the Borough of Altrincham is burned. "The quantities of refuse produced by a given population is insufficient to generate the heat necessary to burn by direct spraying all raw primary settled sewage sludge at 5 percent solids content produced by that same population." The sludge burned is described as "raw primary settled and humus sludge at the rate of 100,000 gallons per seven-day week, i.e., 20,000 gpd on a five-day basis, rising to an estimated 24,000 gpd in the mid 1980's." The refuse population area sludge quantity was estimated as 4.5 times the 380 cu m/day (100,000 gpd) rate for the Borough.

Landfilling, composting, and incineration were considered, and incineration chosen. Quotations were requested including three sludge options: 1) dewatering, 2) external thermal drying, and 3) direct injection of thickened sludge at 5 percent solids. The two low bidders (out of 11) proposed direct injection as their first choice.

The Authority in 1969 surveyed the refuse heating value; it ranged from 6,100 to 7,000 kg-cal/kg (3,400-3,900 Btu/lb). During acceptance testing during December/January following start up, the refuse heating value ranged from 6,700 to 9,400 kg-cal/kg (3,700 to 5,200 Btu/lb), with an everage of 7,700 (4,300). Incinerator design was based upon 8,500 kg-cal/kg (4,700 Btu/lb) refuse (gross heating value presumably as received). The tested ferrous metal content of raw refuse was approximately 7 percent, and this was to be confirmed after several months of operation. (Presumably, these tests were based upon domestic refuse.)

Design allowable incinerator emissions were 0.1 grains per cubic ft @ N.T.P. Ferrous metals are separated from the residue, baled, and sold. Bulky refuse is sheared and returned to the pit. Sludge is macerated and kept in motion prior to injection, to eliminate settlement. Further work on sludge burning is planned.

Notes: Co-incineration at this site has been abandoned because the small sludge injection nozzle continually plugged.

Reference: Defèche, Jean. Combined Disposal of Refuse and Sludges; Technical and Economic Considerations. 1st International Congress on Solid Wastes Disposal and Public Cleansing ISWA - PRAHA '72, Theme V, Pages 3-39, June-July 1972.

Abstract: The paper reports on composting and incineration of MMR and MMS. European sites are identified and the results of brief tests reported. The European sites are:

Cheneviers, Geneva (Switzerland)
Dübendorf (Switzerland)
Bülach (Switzerland)
Dieppe (France)
Bienne (Switzerland)
Horgen (Switzerland)
Männedorf (Switzerland)

The Cheneviers plant in Geneva has two steam-generating incinerators having a nominal capacity of 180 metric ton/day (200 tpd) of domestic refuse. Filter-press-dewatered digested sludge is received from the Aire STP and added to the refuse before burning. "If the proportion of the sludge remains below 20 percent, combustion is stable but difficulties arise with the mixing of the two products."

At Dübendorf, a multiple-hearth sludge incinerator was used for co-incineration. "An attempt" was made to use shredded refuse to supply the required auxiliary heat. There is a similar system in Bulach.

At Dieppe, a von Roll system is being installed. The sludge is dried using a thin-film evaporator. Flue gas or steam can be used in the evaporator.

The remaining plants basically were composing systems were a portion of the wastes could be incinerated.

A series of short term co-incineration tests was conducted at Locarno, Sutton Coldfield, Rotterdam, Zermatt, and Issy-Les-Moulineaux. At all sites but Zermatt, the sludge was added to the refuse before burning; at Zermatt, the 5-10 percent solids mix of primary and secondary sludge was added to the furnace via a rotating atomizer. Various sludges were tried, and most of the test results reported few if any problems. The problems encountered were enumerated as follows:

1. At Rotterdam, the carbon content of the residue increased with co-incineration.

2. At Issy-Les-Moulineaux, poor combustion, sludge sticking to the feed hopper, and a loss of steam production was observed during two tests.

3. At Zermatt, it was difficult to obtain good sludge atomization.

Notes: The Dieppe installation was visited. The Bülach plant was scheduled for a visitation but could not be visited, because the plant was shut down--reportedly permanently, since the manufacturer has decided to abandon this co-incineration approach.

Reference: Eberhardt, H. European Practice in Refuse and Sewage Sludge Disposal by Incineration. Proceedings of ASME 1966 National Incinerator Conference, Pages 124-143, May 1966.

Abstract: This conclusion is pertinent to co-incineration: "The most economical solution for the disposal of all waste products of a housing area is the combustion of sludge together with refuse by using the heat which is released by the combustion for sludge drying." (This process was apparently not in practice at that time.) Common American systems for burning sludge (the multiple hearth, the fluidized bed method, the Raymond flash dryer, and the Passavant Procedure) are discussed. The European Lurgi process is described as follows: "By using the Lurgi procedure...drying sludge is accomplished on vacuum drum filters which are coupled to a centrifuge. Part of the centrifuged substance is sprayed through the flue gas scrubber; the remainder is mixed with the ash in the reaction vessel. The filter cake from the vacuum filter and from the centrifuge is transported into the furnace by means of belt conveyors."

Reference: Edlin, M. A Refuse - Sewage Treatment Works. The American City, Pages 89-91, August 1960.

Abstract: There are two 73 metric ton/day (80 tpd) continuous-feed, traveling-grate-fired refractory incinerators and a Raymond flash drying system at New Albany, Indiana. Sludge conditioned by ferric chloride and lime is vacuum-filtered to a moisture content of 70 percent, and then dried to a moisture content of 8 percent. The dried sludge is shipped out or carried to the refuse incinerators and burned.

Notes: The plant has been shut down.

Reference: Fernandes, J.H. and R.C. Shenk. Solid Waste Fuel Burning in Industry. American Power Conference, April-May 1974.

Abstract: This paper is a general commentary on waste material firing but does represent the current thinking of one vendor--Combustion Engineering. The following is quoted from the paper:

> *Sludge Drying as an Adjunct to a Solid Waste Fired Boiler.* Of special interest is the system...which combines in-plant solid waste burning with plant sludge firing. The shredded solid waste is burned tangentially in suspension with the larger pieces burning on the dump grate at the bottom of the furnace. The sludge is dried from 80% to 15% moisture in a flash drying system and pneumatically conveyed to opposite corners of the boiler to be burned in suspension. The vent gases from the drying system are returned to the upper part of the boiler furnace for deodorization.
>
> Many of the solid wastes found in industry are in the form of sludges having high moisture contents. The system above is designed to dispose of these sludges by predrying and burning without causing air or water pollution or requiring supplemental oil firing.

Reference: Fife, J.A. Sewage Sludge--Another Waste Disposal Problem (Presented at Symposium on Solid Wastes, New York Department of Health, Albany, NY, January 29, 1968.)

Abstract: The author presents a brief review of sludge disposal techniques, including costs and sludge-preconditioning requirements. Improved wastewater treatment will increase the quantity of sludge. Primary sedimentation produces 1.1 cu m (40 cu ft) per 1,000 people per day, or 68 kg (150 lbs) of solids; secondary sedimentation will increase this to 2.5 cu m (90 cu ft) per 1,000 people per day, or 100 kg (225 lbs) of solids. Sludge consistency will be 5 to 6 percent.

Pretreatment is required before any disposal. Operations include gravity settling (most common), flotation, centrifugation, and anaerobic digestion. Thickened sludge is often dewatered further through the use of mechanical equipment such as vacuum filters (most common), screens, pressure filters, and centrifuges. Conditioning chemicals are often used. Sludge cake moisture from secondary thickening ranges from 55 to 80 percent.

Past methods of sludge disposal have included lagooning, ocean disposal, landfilling, and composting. The author suggests sludge incineration as the most desirable means of reducing volume and sterilizing sewage sludge. The most significant sludge variables affecting incinerator design are calorific value, percent solids, percent volatile matter, and percent inerts. Moisture content should be no greater than 75 percent, to insure complete drying and selt-sustaining combustion. Digested sludge combustion is not self-sustaining. Temperatures of 650-760°C (1,200-1,400°F) are required for odor elimination.

Multiple-hearth furnaces, with five to ten hearths, are most widely used. Rotating rabble arms move the sludge around each hearth until the sludge drops to the next lower hearth. Burning sludge at the lower hearths provides the heat input to dry the sludge cake fed at the top. Advantages include moderate operating cost, durability, flexibility to adapt well to fluctuating loads, and the capability of handling screenings and grit.

Flash drying in a cage mill, with direct fuel or refuse burning as the heat source, has also been used. Raw sludge must be dewatered in a vacuum filter or centrifuge. Sludge is flash-dried with 540°C (1,000°F) gases. Dry sludge is recycled to reduce moisture and particle size. Moisture content of sludge from dryer should be no more than 10 percent. This system is of interest only where dried sludge is co-incinerated with refuse to provide heat for the dryer.

Fluidized-bed dryers/incinerators can handle sludge with as little as 10 percent solids, with auxiliary fuel required when burning secondary sludges. Operation should be competitive with multiple-hearth incinerators. Dorr Oliver and Copeland are equipment suppliers. Units have been installed at Lynwood, Washington and East Cliff Sanitary District, California.

Spray dryers/incinerators also appear interesting as a sludge disposal technique, but required feed consistency must be 4.5 to 11 percent solids. Grinding is necessary to reduce particle size to less then 10 microns, for

rapid drying and combustion. Spray units are thermally balanced at 25 percent solids, but sludge cannot be atomized; sludges of lower solids content require supplementary fuel.

Co-incineration of sewage sludge with solid refuse appears to be a workable solution to the disposal of both materials. Logistics must play an important role in incinerator site selection. The following plants have practiced co-incineration.

Plant and Location	Nature of Sludge	Refuse Sludge Ratio
Whitemarsh, Pennsylvania	75% water cake	24:1
Frederick, Maryland	70-75% water cake	2.9:1
Waterbury, Connecticut	Vacuum filter cake	--
Neenah-Menasha, Wisconsin	70% water cake*	4.1
Kewaskum, Wisconsin	Vacuum filter cake	--
Holyoke, Massachusetts	Vacuum filter cake	--

*The 70% water cake is dried to 17% water before firing into traveling grate furnaces.

Another co-incineration plant has been operated at Hershey, Pennsylvania, where sludge is ground, separated by adding oil, evaporated, centrifuged, pressed to 75 percent solids, and then incinerated. A plant in Essen, Germany flash-dries filter-pressed sludge, which is then co-incinerated with solid refuse.

Reference: Gater, D.W. Incinerator is Part of Integrated Waste Disposal System. Public Works 105,5:64-67, May 1974.

Abstract: The 330 metric ton/day (360 tpd) rocking-grate-fired, refractory-wall incinerator at Stamford, Connecticut will burn dried sewage sludge at 20 percent maximum moisture content. Incinerator capacity is 14 metric tons (15 tons) per hour, and they plan to burn 1.4 metric ton (1.5 tons) per hour of dried sludge, i.e. 10 percent of the incinerator capacity. The incinerator is equipped with a spray-cooling chamber and an electrostatic precipitator designed to remove 95 percent of the particulates, reducing an assumed 3.5:1,000 ratio of dust to gas (corrected to 50 percent excess air) to 0.175:1,000. The hot gases will be drawn from the furnace and used to dry the sludge. The spent gases will be returned to the combustion chamber. The dried sludge will be injected through the roof arch and suspension burning is expected.

This co-incinerator is now operational.

Reference: Grop, A. Gemeinsame Verbrennung von Klärschlamm und Müll (Common Incineration of Sewage Sludge and Trash). Brennst Wärme Kraft 17,11:262-564, November 1965.

Abstract: The facility in Franklin, Ohio, partially funded by EPA, is a solid waste plant having a design capacity of 140 metric ton/day (150 tpd). Planned capacity was 36 to 45 metric ton/day (40-50 tpd) of MMR and 6.3 metric ton/day (7 tpd) of sludge.

The process features a "Hydropulper" to shred the municipal refuse. Ferrous and non-ferrous metals, glass, and paper fiber are to be removed ahead of the press feeding the fluid-bed unit. The partially dewatered material from the press is pneumatically conveyed and introduced just above the sand bed of the fluid-bed incinerator. The municipal sewage sludge is burned with the residue from the refuse processing plant.

Reference: Herrmann, W., W.A. Stevens, and E.A. Ramspeck. 1700-MW Dickerson Plant Design Includes Refuse and Sewage Sludge Firing. American Power Conference, April-May (1974).

Abstract: While the Dickerson plant is not operational (still in the design stage), it is of interest since it will be a fossil-fuel-fired steam generator arranged to burn both shredded refuse and sewage sludge wet solids.

There are two 850-MW gross base load, coal-fired, steam-generating units side by side. The furnaces are Combustion Engineering tangentially fired units, 14.2 m deep, 29.6 m wide, and 58.2 m high (46½' x 97' x 191'). The furnace combustion rate is 1,240 kg-cal/cu m (11,080 Btu/cu ft) per hour. The net heat release rate is 27,000 kg-cal/sq m (72,400 Btu/sq ft) per hour to the vertical furnace outlet plane. The analysis of the Eastern bituminous coal to be burned is as follows:

Proximate Analysis (percent)	Typical	Range
Moisture	7.0	2-12
Ash	14.0	10-25
Volatile Matter	21.0	15-35
Fixed Carbon	58.0	
Total	100.0	
Sulfur	1.91	0.5-3.5
Higher heating value, as fired		
kg-cal/kg	22,000	20,000-23,000
Btu/lb	12,000	11,000-13,000
Grindability, hardgrove	60	50-100
Minimum ash softening temperature H-W (reducing atmosphere)	1,150°C (2,100°F)	

The coal is pulverized in seven bowl mills, each having a capacity of 64,000 kg (140,000 lb) per hour when grinding the typical coal to a fineness of 70 percent less than 200 mesh. The pulverized coal is delivered to the furnace through 56 41-cm (16") fuel pipes and admitted to the furnace located in the front and rear walls of the divided furnace. Each pulverizer supplies a single elevation of coal nozzles, one per windbox. The 66-cm (26") wide windbox will have an overall height of 12.8 m (42 ft). Shredded municipal refuse (from which glass, sand, and metals has been removed) may be fired initially at a rate of up to 10 percent of the maximum continuous Btu input to the furnace. Typical municipal refuse ranges in heating value from 7,200 to 9,000 kg-cal/kg (4,000-5,000 Btu/lb). The shredded refuse will be pneumatically introduced to the top level of the eight windboxes. Thus, all the fossil fuel firing will take place below the level of municipal refuse injection. Each of the boilers' corners will have a refuse nozzle and a separate refuse conveying system.

Up to 23,000 kg (50,000 lb) per hour of wet organic sewage sludge from the neighboring advanced waste treatment plant can be incinerated. The sludge will contain approximately 87 percent moisture (13 percent solids) when received by pipeline at the boiler. The sludge has a heating value of approximately 13,000 kg-cal/kg (7,000 Btu/lb) on a dry basis. Heat input from sewage sludge dry solids thus will amount to approximately 0.5 percent of the unit's maximum continuous rated heat input; this will be approximately equivalent to the heat required to evaporate the sludge moisture. To avoid possible plugging problems, the sewage must not contain more than 25 percent solids at a size of 100 percent minus eight mesh and 90 percent minus thirty mesh. The sewage sludge will be injected into the furnaces through two sewage sludge guns located in opposite corners of each furnace half and at an elevation of approximately half of the windbox height. Thus, four coal nozzles will be positioned below the point of sludge injection, and three coal nozzles above.

Fly ash will be removed by a high-temperature precipitator, and the performance of the hot precipitator is expected to be 99.6 percent removal, based upon 25 percent ash, 0.7 percent sulfur coal, and one electrical set out of service in each gas lane. Each gas lane of the precipitator will also be equipped with an inlet damper so that overall precipitator performance can be maintained, at reduced load, in the event of a serious electrical failure in any particular lane.

Sulfur oxide removal is to be accomplished by a wet-scrubber system, to accomplish 90 percent removal of the SO_2 in the flue gas with an inlet SO_2 concentration of 1,000 ppm or more. According to the paper, the specific SO_2 removal system had not been selected, but the user was looking at the magnesium oxide process. A news release since that time indicates that the user (Pepco) has signed a contract with Basic Chemicals for the processing of magnesium sludge from the SO_2 scrubber.

Reference: Hescheles, C.A. Disposal of Wastes from Industrial Plants. ASME Paper 69 - Pwr 1, ASME-IEEE Power Conference, Charlotte, NC, September 1969.

Abstract: The author reviews refuse and sludge disposal techniques and presents two concepts for combined disposal of refuse, sludge, and waste liquids in a spreader/stoker-fired furnace.

Reference: Hescheles, C.A. and S.L. Zied. Investigation of Three Systems to Dry and Incinerate Sludge. Proceedings and Discussions of ASME 1972 National Incinerator Conference, pp. 265-280 (1972).

Abstract: Three Sludge Incineration Systems are compared: Fludized-Bed, Multiple-Hearth, and Rotary Kiln Furnaces. The Fluidized-Bed System consists of a reactor, a dry collector, and a scrubber. The Multiple-Hearth System has a scrubber, and the third system consists of two rotary kilns: one for sludge drying and the other for incineration; a scrubber is also used with the kilns. The three systems were evaluated on industrial and sanitary sludges, and operating cost estimates were reported, indicating that the Rotary Kiln Furnace is significantly cheaper than the Fluidized-Bed system and somewhat cheaper than the Multiple Hearth. Annual costs per 1,000 kg (1,000 lb) of solids were estimated as follows:

Rotary Kiln	\$56.00 (\$25.50)
Fluidized Bed	\$91.00 (\$41.50)
Multiple Hearth	\$65.00 (\$29.50)

Reference: Joachim, O.H. Energie aus Müll unter besonderer Betrachtung der Nutzung zur Klärschlammtrocknung (Energy from Refuse in Particular Consideration of its Utilization for Sludge Drying). Aufbereitungs Technik 65: 279-283, May 1965.

Abstract: The author describes two sludge-drying schemes--one of which has been installed at Gluckstadt, West Germany, using drag-flight conveyors. The double pass (counter and co-current) direct contact system and the co-current indirect contact dryer are both heated by the refuse flue gas. Either may be used or they may be combined, with the off-gas or vapor going back into the furnace. The author shows a catalytic after-burner in the return gas stream as an option. He states the dried sludge may be incinerated but provides no details.

Reference: Kiefer, B. Gemeinsame Aufbereitung von Klärschlamm und Müll (The Joint Elimination of Sewage Sludge and Waste). Stadtehygien 16,8:179-181, August 1965.

Abstract: At the Ebingen plant, the refuse is first crushed in a hammer mill and cleaned magnetically, then added at the second and third levels of a Story (Multiple Hearth) furnace; the sludge is added to the uppermost hearth. The ratio is 100 tons waste per 36 tons sludge. The sludge is dewatered to 60-65 percent water. The additional energy necessary for incineration at 700-800°C (1,300-1,500°F) is introduced in the third and fourth levels (incineration zone). The sludge is predried in the two upper levels of the furnace; at the sixth and seventh level the furnace air is preheated and the ash is cooled. The flue gases, at 600°C (1,100°F), go to a wet scrubber.

Reference: Knaak, R. and R. Kuhl. Ergebnisse der Grossversuche mit gemeinsamer Verbrennung von Müll und Klärschlamn in den Müllverbrennungsanlagen Kopenhagen und Bonn-Bad Godesberg (Results of Large-scale Experiments with Joint Incineration of Refuse and Sewage Sludge in the Incinerators of Kopenhagen and Bonn - Bad Godesberg). VGB Kraftwerkstechnik 53,4:210-213, April 1973.

Abstract: Experiments were conducted at the Gentofte incinerator in Copenhagen and at Bad Godesberg to investigate whether sludge can be incinerated jointly with household refuse, which would reduce disposal cost and obviate the need to dehydrate the sludge to the degree required by current processing.

The 270 metric ton/day (300 tpd) Bonn-Bad Godesberg plant is a steam-generating, grate-kiln-fired, continuous-feed incinerator. The Copenhagen incinerator is similar. Four sludges and several dewatering processes were used, and the sludge was added to the furnaces at 47-48 percent moisture. Some sludge was continuously added to the refuse by a spreader; other sludge was mixed with the refuse in a trommel and fed to the furnace; at least one full bucket of sludge was placed in the feed chute; and sludge was also placed manually (by shovel) into the feed chute during one test sequence. The only problem reported was the formation of crusts that hindered the drying and burning of these pieces.

It is also pointed out that waste components such as cans, glass, organics, etc. help to break up the refuse, similar to the action of the balls in a ball mill. It is very important to have a good mixture of sludge and refuse.

Reference: Komline, T.R. Sludge Incineration. U.S. Patent No. 3,322,979, dated May 30, 1967.

Abstract: This patent describes a combined solid waste incinerator and sewage sludge spray dryer.

Solid refuse is burned in an elongated, traveling-grate incinerator. Above the incinerator housing is a cylindrical shell, typical of spray-drying towers. The bottom of this tower opens into the combustion area of the incinerator, over the traveling grate. Sewage sludge (no consistency reported) is injected into the top of the tower (most likely through a disc atomizer). The atomizer must be capable of dispersing the sludge into finely divided particles, to promote rapid drying. Some of the hot combustion gases are withdrawn from over the burning refuse through a blower. The hot gases are tangentially directed into the spray tower; the gases provide the heat input necessary to dry the sludge. Temperatures should be high enough to permit combustion of smaller sludge particles in the drying tower. Heavier particles not burned will evenly deposit over the burning refuse, traveling beneath the drying chamber. These particles will have been dried and will remove little additional heat from the burning solid refuse.

Gases from the drying chamber are directed downward and across the burning refuse. Temperature should be maintained at 760°C (1,400°F) to ensure combustion of all odorous materials from sludge drying. A baffle across the incinerator solid waste combustion zone helps to divert the drier gases into the combustion zone. The inventor claims that the baffle also reduces the particulates entrained in the blower supplying the air to the dryer section.

No operating conditions for sludge and solid waste restrictions were noted in the patent. No estimate of the sludge to solid waste ratio was recorded.

Comments: This type of facility appears somewhat limited in practice. Sludge consistency will have to be very low to get good atomization. Even with best disbursement of sludge, contact time does not appear adequate to achieve good drying. In view of the rapid cooling of the gases, combustion is not likely to start in the spray drying section. Deposits of sludge on the walls of the dryer would be a serious problem. Cooled gases from the dryer pass into the combustion zone; this cooling may result in poor combustion, and dryer gases may also be short-circuited back into the dryer with loss of drying capacity. This unit would appear to have a very low sludge-to-waste-solids ratio.

Reference: Kuchta, H.D. Veraschungsanlage für olhaltige Schlamme und Rechengot nach dem Drehrohrofensprinzip (Incinerator for Oily Sludges and Refuse Using a Rotary Kiln). Brennst. Warme Kraft 18,5:244-247, May 1966.

Abstract: A co-current rotary kiln installed in 1962 at Cologne, Germany. The kiln was designed to burn 65 metric tons/day (72 tpd) of oil sludge and some small refuse. After installation, the kiln was lengthened in 1963. The quantity of refuse is not stated, and only small solids are fed. The original screw feeder was replaced with an inclined chute feed method. The unit was designed to burn waste oil, but availability problems forced a switch to methane gas burning. The author reports kiln preheating problems and great difficulty in maintaining proper combustion temperatures. The author concludes that uniform, complete combustion is possible only if the refuse is shredded, well mixed with the sludge, and uniformly fed to the furnace.

Reference: Kurney, W. Die gemeinsame Aufbereitung von Feststaffabfällen und Klärschlamm für die Rottendeponie, Kompostierung und Verbrennung (Common Treatment of Solids Waste and Sanitary and Industrial Sludge for Disposal on Rotting Stockpiles for Composting and Incineration). Aufbeitungs-Technik 5:255-260 (1971).

Abstract: The Hazemag impact mill was modified to make possible the reduction of refuse and industrial waste. The author claims that this permits mixing solid wastes and sanitary and industrial sludge while comminuting them in the impact mill.

Reference: Lancoud, F. Combined Disposal of Refuse and Sludges; Technical and Economic Considerations. 1st International Congress on Solid Waste Disposal and Public Cleansing, ISWA Praha 1972, Thema V. June-July 1972.

Abstract: The MMR furnace in Geneva, Switzerland was installed in 1967 to burn refuse and sludge. Raw sludge at 5 percent consistency was thermally pretreated at 180°C (356°F) and then filter pressed 6.9 bar (100 psi) producing sludge cakes containing 40 percent moisture. The cakes were broken to a size of about 20 sq cm by 4 cm thick (7.9 in. by 3.9 in.).

The sludge was to be burned in a 180 metric tons/day (200-tpd) continuous-feed, grate-fired, steam-generating incinerator with oscillating knives to improve combustion. The incinerator manufacturer estimated that input could contain up to 20 percent pretreated sludge cakes without affecting combustion. However, there appeared to be an excessive amount of combustibles remaining in the ash. In June 1969, tests were run on the incinerator burning refuse alone and refuse containing 10 percent (by weight) sludge cakes. The composition of the sludge cakes, refuse, and ash from two tests is listed below:

Sludge Analysis

Item	Amount (percent)
Water	41
Ash	40.3
Combustion material	18.7
Fixed carbon	6.5
Volatile substances	12.2

The specific energy of the sludge was 645 kg-cal/kg (358 Btu/lb); of the combustible material, 4,763 kg-cal/kg (2,645 Btu/lb).

Refuse Analysis (percent)

Item	First Test	Second Test
Water	25.2	28.5
Ash	27.7	34.7
Combustible material	47.1	36.8
Fixed carbon	9.0	6.9
Volatile substances	38.1	29.9

The specific energy of the dried refuse was as follows:

	First Test	Second Test
Dried Refuse		
kg-cal/kg	1,914	1,336
Btu/lb	1,062	2,273
Combustible material		
kg-cal/kg	4,392	4,096
Btu/lb	2,438	741

Residue Analysis (percent)

Item	First Test (No Sludge)	Second Test 10% Sludge Added
Production of remaining ashes	40.65	55.85
Water Content	26.3	26.9
Ash	71.6	68.9
Combustible material	2.1	4.9
Fixed carbon	1.0	2.5
Volatile substances	1.1	2.4

The data indicate that when refuse is burned alone, the ash contained only 2 percent combustibles, but when sludge cakes were included, the residue contained almost 5 percent combustibles. It was assumed that the increased combustible material resulted solely from the sludge. A combustible material balance indicates that none of the sludge was incinerated. A carbon balance revealed that only 12.6 percent of the available carbon in the sludge was burned.

Carbon Analysis (percent)

Values	First Test (No Sludge)	Second Test (10% Sludge)
Carbon in refuse	23.73	18.2
Carbon in sludge cakes	--	10.48
Carbon in dried remaining ashes	2.95	3.94
Weights of carbon in:		
Refuse	21.5	17.3
Sludge cake	--	1.03
Dried ashes	0.885	1.61

The tests indicated that the sludge was not satisfactorily destroyed by incineration, because:

1. Larger pieces of sludge cake move faster than refuse through the furnace; thus, burning time is reduced.

2. A crust formed on the sludge cake, hindering complete combustion.

3. Poor mixing permitted sludge cakes to separate from the refuse, with poor air contact and resulting poor combustion.

Suggested remedial action:

1. Reduce size of sludge cakes to 2 cm (3/4 in.) or less.
2. Employ mechanical action in incinerator to break crusted cakes.
3. Improve mixing of sludge cakes and refuse.

Reference: Martin, W.S. Sludge and Refuse Disposal. U.S. Patent No. 2,483,918, dated October 4, 1949.

Abstract: The author describes a cylindrical incinerator for the combined combustion of solid waste, and the drying/combustion of sewage sludge.

The base of this incinerator is designed with a stationary, circular grate. Trash is charged from above through a circular flue. A rotary stoker (10-20 rev/hr) with radial fins continually moves the burning refuse outward, with ash discharge downward through the grate. Combustion air is preheated in a waste heat exchanger. The heated combustion air is supplied to the incinerator through the grate, under the stoker drive, through the stoker fins, and also through a cone housing mounted above the stoker. The preheated air improves combustion of the waste with the air brought through the stoker fins, to dry the refuse before combustion. Hot gases travel upward through the combustion chamber.

Directly above the combustion chamber is a circular sludge-drying zone. Sludge with a consistency of 10-50 percent is charged to a rotating, annular hearth. This sludge is spread and continually agitated by stationary rabble arms, mounted above the rotating hearth. A portion of the combustion gases is drawn off below the drying hearth, the remainder passing through the center opening into the hearth area, where the sludge is dried. In addition to conductive heat transfer, considerable heat is transferred to the sludge by radiation from the hot firebrick above and around the drying-hearth area. The rabble arms continually move the sludge towards the center opening. When dry, it falls from the drying hearth into the solid waste combustion zone.

Vapors escaping from the drying hearth are combined with hot gases from the burning refuse in a secondary combustion zone, where any noxious materials in the sludge vapors are destroyed. Hot gases pass through a heat exchanger to preheat the incoming combustion air, and the hot gases then go out to the atmosphere.

Notes: Sludge drying in this incinerator appears to be inefficient. There is very little contact between the wet sludge and hot combustion gases. Radiant heat transfer from the incinerator walls provides surface drying only. Much of the mechanical equipment inside the incinerator might be a serious maintenace problem.

Such a furnace was installed in 1950 at Gloucester City, NJ, and was reportedly operated successfully, but has since been shut down.

Reference: Matsumoto, K. et al. The Practice of Refuse Incineration in Japan -- Burning of Refuse with High Moisture Content and Low Calorific Value. Proceedings of ASME National Incinerator Conference, pp 180-197 (1968).

Abstract: Solid refuse in Japan contains 40 to 70 percent moisture while typical American or European refuse contains only 10 to 45 percent moisture. This is due to the significant amounts of garbage (waste food) in Japanese solid waste. Predrying is required before incineration.

Two predrying methods are used: hot-air and hot-gas, both assisted by direct-fired surface drying. In hot-air systems, preheated air is forced through the refuse in a typical grate-fired incinerator. There may be problems with ignition of some of the refuse on the drying grate. Hot-gas drying recirculates part of the combustion gases through the refuse. Since oxygen in the spent gases is low, ignition temperature is much higher, and early ignition is not a problem. Higher temperatures also promote more efficient drying. These are more complex than air-drying incinerators.

The following is taken from the paper:

> The difference between these methods is the drying equipment. In the hot-gas method there is no fear of blow-off (crater) due to partial burning of the refuse layer, and a conventional and reliable traveling grate stoker can be employed. Since the refuse partially burns in the hot-air method, a reciprocating stoker which properly shakes the refuse layers must be used to prevent blow-off (crater).
>
> There are various types of reciprocating stokers. As classified according to type of stoker, the mechanical incinerators in Japan can be generally classified into following types:

- Traveling grate stoker (1)
- Chain grate stoker (1)
- Reciprocating stokers: (Gas drying = 1)
  - Stepped grate stokers (1, 2)
  - Shaking stokers (1, 2)
    (von Roll type)
  - Rocker action grate stokers (1, 2) (Air drying = 2)
- Rotating grate stoker (VKW type) (1, 2)
- Rotary kiln stoker (1, 2)

The authors state that recirculated gas drying has the following advantages:

- Flue gas with temperatures higher than air temperatures can be employed as the drying medium.
- The CO_2 content of the combustion gas can be increased, and the required capacity of the gas exhaust system can be materially reduced.

- Greater drying heat can be applied at the same temperatures because the specific heat capacity of the flue gas with its higher moisture content is higher than that of air.

- Excessive furnace temperature rise can be prevented by controlling the amount of recirculating gas.

Reference: McMullen, F.G. Waste Materials Processing System. U.S. Patent No. 3,769,921, dated November 6, 1973.

Abstract: The inventor describes a method of incinerating solid waste using a combination of solid waste combustion on a traveling grate, and suspension combustion of pulverized solid waste. Pre-dried sewage sludge can also be burned. A portion of the heat generated is used in the pyrolysis of additional pulverized solid material, to generate recoverable products.

Trash with a density of 225-255 kg/cu m (14-16 lb/cu ft) -- no moisture specification -- is burned in a typical inclined, moving-grate incinerator. Pulverized waste material (no pulverizing equipment specified) with a density of 255-320 kg/cu m (16-20 lb/cu ft) and a moisture content of 20-25 percent is pneumatically injected into the combustion zone. Approximately 80 percent of the pulverized waste is suspension-burned, with combustion air supplied by the pneumatic injection system. The 20 percent falling to the grate has combustion air supplied through the grate system. The quantity of pulverizer trash burned will be regulated by the steam demand on the waste heat boiler.

Sewage sludge, pre-conditioned to a 15 percent moisture content, is also pneumatically injected into the combustion zone above the grate.

Heat generated during combustion can be used for steam generation or for pyrolysis of additional pulverized waste material. Gases from the pyrolysis unit are cleaned in consecutive acid and caustic scrubbers, dried, and light hydrocarbons are then recovered. Waste heat from the boiler is used in a flash dryer to dewater the sewage sludge to an 85 percent consistency. Few details are provided for the dewatering step.

Notes: This patent utilizes processes that are not relatively new; rather, the patent is a combination of existing incinerator technology. The scheme for recovery of pyrolysis gases appears questionable. After steam generation and combustion air preheating, heat remaining in the combustion gases for evaporation of water from sewage sludge is very limited.

Reference: Moegling, E. Praxis der zentralen Mülverbrennung am Beispiel Essen - Karnap (Experience with Central Refuse Incineration at Essen-Karnap). Brennst Wärme Kraft. 17,8:383-391, August 1965.

Abstract: A plant at Essen-Karnap, W. Germany was designed to burn 2,200 metric tons/day (2,400 tpd) of refuse and 1,360-1,910 metric tons/day (1,500-2,100 tpd) of sludge. (See abstract of Weyrauch paper, May 1962.)

Reference: Munro, C.S.H. and T.J.K. Rolfe. The Incineration of Sewage Sludge with Domestic Refuse on a Continuous Burning Grate. (Part of a

Symposium held at the University of York, Yorkshire, England); The Institution of Chemical Engineers Symposium Series No. 41, pgs. 3.1-3.34, April 1975.

Abstract: The authors review sludge origins, treatment, dewatering, and disposal techniques. They cite two basic methods of introducing sludge into a refuse incinerator: 1) Spraying thickened sludge into the furnace above the refuse bed; and 2) by mixture of the sludge cake with the refuse on the grate. They mention three modern refuse incineration plants in the U.K. where sludge is being burned or planned for; these are Altrincham, Reigate, and Havant.

The proposed Havant co-incineration system is further described. Tests were conducted using dual-fluid spray nozzles to atomize thickened sludge. The tests were conducted with 3.5 percent solids sludge, but thicker sludge is expected at the site. The thickened sludge would be injected over the refuse grate to dry and burn in suspension. The sludge will pass through disintegrators en route to the spray nozzles. Furnace exhaust temperature will be maintained at 830°C (1,525°F) to ensure odor destruction and to maintain the combustion of sludge moisture and low excess air rates used to control furnace temperatures. The system is expected to be operational late in 1975.

Reference: Nickerson, R.D. Sludge drying and incineration. Journal of the Water Pollution Control Federation 32,1:90-98, January 1960.

Abstract: The system at Waterbury, Connecticut consists of a circular-type refuse incinerator and a Raymond flash dryer system. Raw primary sludge is vacuum filtered. "The sludge is very fibrous. The average grease content on a dry solids basis has ranged from 23.0 percent in 1956 to 26.3 percent in 1953. It was 23.5 percent in 1957."

The grease and fiber make the material unfit for soil conditioning.

Comments: The original plant was installed in the mid- 1950's. The sludge at Waterbury contains significant quantities of oils and greases, which are not characteristic of ordinary municipal sludge. As originally installed, the sludge being dried was from a primary plant. However, Waterbury has since gone to secondary treatment, and as a part of the secondary treatment system multiple-hearth furnaces were installed. Hence, the waste sludge is not burned in the multiple-hearth units. Note that the Raymond flash drying system, while not in use, could be used.

Reference: Novak, R.G. Eliminating or Disposing of Industrial Solid Wastes. Chemical Engineering, Pages 78-82, October 5, 1970.

Abstract: Dow Chemical Company's industrial solid wastes (including drums and high and low-Btu liquid wastes) are burned in a 16 x 10^6 kg-cal/hr (65 MM Btu/hr) rotary-kiln incinerator. Combustion is completed in a stationary secondary combustion chamber. The high-Btu liquid wastes are concurrently fired to ensure burn-out of the largely plastic solid wastes and low-Btu liquids.

Note: Dow was preparing a second rotary kiln incinerator for operation, with a target date May of 1975. The new kiln installation was to be very similar to the present system, and would handle tars, refuse and biological sludge.

Reference: Palm, R. Gedanken zur kombinierten Schlamm- und Müllverbrennung in Rostfeuerungen (Ideas on the combined Combustion of Sludge and Waste Products in Grate Fires). Brennst-Wärme-Kraft 18,5:223-226, May 1966.

Abstract: There has been little progress, to date, in combining the combustion of sewage sludge and solid refuse. This is due to the lack of knowledge: how the wide variations in sludge composition affect the combustion process; the characteristics of the slag; and the effects of the products of combustion. The article discusses the special difficulties encountered from the point where the charge is prepared, and considers ignition and the combustion process through to the end product. A number of types of sludge are discussed with regard to compostion, ignition, and combustion.

Reference: Pepperman, C.M. The Harrisburg Incinerator: A Systems Approach. Proceedings of the ASME National Incinerator Conference, 1974.

Abstract: The Harrisburg, Pennsylvania incinerator consists of two 272 metric ton/day (300-tpd) continuous-feed, stoker-fired, steam-generating incinerators. Plans are underway to heat-treat, vacuum-filter, and dry the sewage sludge in an evaporator or steam dryer to a moisture content of about ten percent. The dried sludge will be pneumatically conveyed and injected into the furnaces and burned in suspension. "Based on an operating schedule of 120 hours per week for the dewatering and drying facilities, the refuse incinerator will be required to burn 3,410 pounds of dry sewage solids at the design sewage flow of 30.9 mgd. Because of its high heating value, it is estimated that when dried sludge is burned, it will release sufficient heat to generate 13,600 pounds of steam per hour, which is only slightly less than the quantity of steam needed to heat-treat and dry the sludge and heat the building."

Reference: Rathgeber, F. Müllverbrennung mit und ohne Energiegewinnung (Waste Incineration with and without Energy Production). Wasser Luft und Betrieb 17,9:295-301 (1973).

Abstract: The following is quotation from the translation of the paper, concerning "Combined incineration of refuse and settled sludge":

> Anti-pollution centers have the purpose of removing, with respect to rendering harmless, both refuse and settled sludge. With correct planning, such plants also provide extensive heat utilization. The use of waste gases from refuse incineration makes the mechanical removal of water from previously 'conditioned' sludge more feasible. Subsequently, it can also be dried by the use of hot waste gases, so that it can be burned.
>
> A thermal process (Seiler-Koppers system) facilitates the drying of fresh sludge, noxious sludge, and aerobically stablized, biologically active sludge from community sewage treatment. Under certain conditions, it is also possible to dry sludge from factory or industrial sewage

treatment plants. At the outset, the sludge has an initial water content of 50-90 percent, but it is only 5-15 percent after drying. The drum dryer consists of three concentric cylinders. They are equipped with longitudinal ribs with a saw-tooth-profile cross section. Air, and the sludge to be dried, are rotated within the drum by 180° twice. The sludge particles, now dry and, therefore, lighter in weight, are continuously sucked away. The dried material, as well as the sucked-away air with the vapors, are brought into a cyclone in which the dried material is removed from the air and the vapors. After being separated, the dried material is transported to a storage silo or, possibly, back to the double shaft mixer installed ahead of the dryer. Here it is mixed with the wet sludge and recirculated to the dry drum. According to need for supply, the dried matter can be placed in paper bags or put into a storage silo.

In combined refuse and sludge incinerators, the waste gases can be used for thermal drying of the sludge in the installation described above. The dried sludge can be sold as germ-free soil-improving material, or incinerated with the refuse. The vapors form the dryer are also introduced into the furnace in order to destroy malodorous substances. Where the local conditions do not permit the use of dried sludge, and the proportion of settled sludge to refuse is low, an incinerator combining grates with a rotary drum as the next stage is recommended. This eliminates the sludge dryer. In such cases, the water content of sludge is reduced 70-80 percent by purely mechanical means, and the sludge is burned with the refuse. Incineration tests in various plants have shown that up to 20 percent of merely mechancial-dried sludge can be added to the refuse. Good combustion is still achieved by these proportions; the furnace temperature does not drop below 850°C. This temperature is necessary to ensure the breakdown of malodouous material.

A plant built for an association in Switzerland solved the problem of sludge removal. Since this plant deals with large quantities of industrial sewage, it was impossible to break the sludge down biologically. It is therefore dried and burned. Vacuum filters are used for water removal. After a flocculation agent and lime are added to the sludge, the filters reduce the water content to approximately 70 percent. The dried sludge is carried to an incinerator drum which combines a dryer and a furnace portion lined with refractory material in one unit. In future expansion plans, the waste gases from a yet-to-be-built refuse incinerator will be used to dry and incinerate the sludge. Until this facility is built, the requisite temperatures are achieved by fuel oil. The resulting vapors are first rendered dust-free in a washer, after which the malodorous substances are removed in a catalytic after-burner. A fuel-saving temperature of approximately 300°C is sufficient.

Reference: Reilly, B.B. Incinerator and Sewage Treatment Plant Work Together. Public Works 92,7:109-110, July 1961.

Abstract: The original Whitemarsh Township, Pennsylvania incinerator was a refractory-wall furnace with tubes buried in the refractory walls in order to cool the walls. The 272 metric ton/day (300-tpd) furnace was a stoker-fired. continuous-feed unit, and was equipped with an impingement-tray-type scrubber.

The raw sludge from the adjacent STP was dewatered, using a vacuum filter, before being mixed with the refuse. The sludge is both primary and secondary from the trickling filter STP. The sludge cake from the vacuum filter was mechanically mixed with the refuse before burning. No details on the mixing device were included in the article.

Design conditions were as follows: "At design loads, the breakdown is 10.9 metric ton/hr (12 ton/hr) of refuse and 0.45 metric ton (0.5 ton) of sludge. Thus, even though the sludge cake is 75 percent water, only 0.34 metric ton (0.38 ton) of moisture is added to the charge, resulting in a total moisture increase of three percent."

Performance test data are as follows:

Interval: Five operating days, September 22-28

Total Refuse Burned: 346.7 metric tons (381.4 tons)

Total Sludge Burned: 29.1 metric tons (32.0 tons)

Total hours operated: 31.5

Combustible material not destroyed: 4.36 percent

Particulate matter in stack gas: 0.0572 kg 1,000 kg of gas, or 69.8 mg per std cu m of gas (0.0305 grains per std cu ft of gas).

Thus the sludge-to-refuse ratio in design was 4.2 percent, and they achieved 8.3 percent under test conditions. As the sewer system was a new one, a high proportion of mud appeared in the sludge.

Note: The Whitemarsh incinerator was extensively rebuilt and it is understood they have not attempted to burn sludge since the rebuilding and, in fact, probably did not use it extensively for sludge originally. The reasons are unknown.

Reference: Rüb, F. Moeglichkeiten und Beispiele der kombinierten Verbrennung von Müll und Abwässerschlamm (Possibilities and Examples of a Combined Incineration of Refuse and Waste Sludge). Wasser Luft and Betrieb 14,12:484-488, December 1970.

Abstract: Four of the five systems briefly described are burning sludge and refuse. These four are:

1. Multiple hearth, with MSS added to shredded MMR before charging top hearth (Uzwil, Switzerland)

2. Multiple hearth, with MSS dried on upper hearths and shredded MMR charged to mid-hearths; lower hearths cool ash and preheat combustion air. (Zurich, Switzerland)

3. Keller-Peukert system (similar to Raymond flash drying system), where the dried sludge is metered into the charge hopper of the refuse furnace. The dryer uses hot air that passes through a heat exchanger at the refuse furnace exhaust. The dryer vent gases are introduced into the windbox under the refuse furnace grate system.

4. Rotary kiln system handling sludge and refuse.

Reference: Salamon, O. Process for the Concomitant Incineration of Solid Refuse and of Aqueous Sewage Sludge. U.S. Patent No. 3,552,333, dated January 5, 1971.

Abstract: The inventor proposes a method of drying sewage sludge in a thin-film evaporator, utilizing heat generated by the combustion of solid waste. The dried sludge is then to be incinerated along with the solid waste fuel.

Per capita solid waste is estimated at 0.68-2.0 kg/day (1.5-4.5 lb/day), with a heating value of 1,000-2,500 kg-cal/kg (1,800-4,500 Btu/lb). At the same time, 1.0-2.0 kg/day (2.2-4.4 lb/day) of 8 percent consistency sewage sludge per person are generated. The inventor estimates that only 60 percent of the potential heating value in the solid waste can be used for evaporation purposes (430-3,020 kg-cal -- 1,700-12,000 Btu -- per person per day), due to the need to maintain a gas temperature of 300°C (570°F). Heat required for evaporation and superheating of a per diem quantity of sludge is estimated at 600-1,310 kg-cal (2,600-5,200 Btu) per person per day (further reduced to 500-1,160 kg-cal -- 2,000-4,600 Btu -- if the solid residue is also burned).

The sludge is to be pre-dried in a thin-film evaporator before combustion. No details of the evaporator are provided. Combustion gases provide the heat input into the evaporator. Heat is supplied directly from the hot gases or through the use of an intermediate waste-heat boiler which produces steam to drive the evaporator. In addition, multi-effect evaporators are proposed to increase the quantity of sludge which can be evaporated with same heat input. The incoming sludge has a consistency of 8 percent. As described, the sludge is almost completely dried. Sludge solids are then mixed with solid waste refuse and burned in the incinerator.

Notes: Complete drying of waste sludge, even in a thin-film, wiped-surface evaporator, would be a serious problem because of charring of the sludge on the evaporator walls. Multi-effect evaporators operate only when there is a boiling point elevation in the material being evaporated. In a two-phase sludge case, this is probably not the case. Even if effective, multi-effect evaporation leaves the condensed vapor from the second effect, and would contain noxious materials and would have to be returned to the sewage treatment plant.

Reference: Samuels, L.J. New Look at Sewage Disposal. Western Precipitation Group, Joy Manufacturing Co., Los Angeles, California (No date).

Abstract: This equipment supplier suggests predrying sludge in its Holo-Flite conveying dryer before landfill disposal or incineration. The conveying dryer has a jacketed shell and hollow screws, which were heated by 320°C (600°F) oil during their experiments. Digested sludge at 62.7 percent moisture and vacuum-filtered raw sewage sludge at 75.5 percent moisture were dried in pilot-scale equipment. Heat transfer coefficients ranged from 170-56.8 W/sq m - °C (30 to 10 Btu/hr-°F-sq ft) and dropped rapidly with loss of moisture in the sludge.

On a commercial basis, they suggest using a five-pass unit (7.9 m -- 26 ft long) to dry 11,360 kg (25,000 lb) of raw sludge from 77 percent to 25 percent moisture. After drying, the sludge can be disposed of in landfill or incinerated to make up the heat for drying.

Notes: Although they report no deposits in the dryer, test runs were only one hour. Charring of the surfaces and further loss of heat transfer should be expected. Evaporation of the water (not counting preheating to 100°C -- 212°F) requires 85 percent of heat value of the sludge solids. While this would appear to balance, no consideration is given to heat losses from equipment, enthalpy of stack gas, or heat content of the ashes.

Reference: Schlotmann, W. Klarschlamm, seine Behandlung und Beseitigung Speziell durch gemeinsame Müll-Klärschlamm-Verbrennung (Sewage Sludge, its Treatment and Disposal Especially Through Combined Refuse -- Sludge Incineration). Het Ingenieursblad, 42,10:304-312, May 1973.

Abstract: Mostly theoretical and state-of-the-art. Co-incineration is advantageous. Sludge-to-refuse ratios are given, considering heat values and moisture content. The process yields sterile ashes which are dumped.

Five combinations of processes to co-incineration refuse and sludge are discussed:

1. Sludge having a water content of 90-96 percent, coming directly from the thickener, is delivered directly to the incinerator. The sludge has to be prepared to incineration with the refuse. This is to be done with optimal utilization of the excess heat from the refuse incineration. The sludge first goes into a heat exchanger, then into a thin-layer drier; by then, it has a moisture content of 40-60 percent. The vapors go into the incinerator and are heated to 800°C (1,470°F). The sludge is further dried in a mill-drier. In the second drying step the water is reduced to 15-20 percent. The sludge is then blown into the incinerator.

2. The sludge is mechanically dewatered (60-75 percent), then goes to the crusher-drier and is dried to a maximum of 20 percent with hot air from a heat exchanger. Depending on the ratio of sludge-to-refuse, the dried material is blown directly into the incinerator

with the drier air and the vapors; otherwise, there would be a separation of the dried sludge from the arivapor mixture.

3. A mill is used in place of the crusher-drier. This is practical only for large amounts of sludge.

4. Sludges coming from two different plans are to be processed. Plant 1 is quite close to the incinerator. Plant 2 is 10-14 km (6.3-8.8 mi) away from the incinerator.

    a) The sludge was transported as liquid.

    b) The sludge was dewatered mechanically and the filter cake was transported.

5. Sludge and refuse are co-incinerated. In addition, sludge is also incinerated by itself in a fluid-bed incinerator, after being mechanically dewatered.

Reference: Synder, N.W. Energy Recovery and Resource Recycling. Chemical Engineering, pp. 65-72, October 21, 1974.

Abstract: The author reviews the status of the various solid-waste disposal plants, some considered advanced technology and others considered experimental technology. There is specific mention of the use of dewatered sewage sludge in the demonstration plant for the Purox process being piloted on a full scale by Union Carbide Corporation's Linde Division in South Charleston, West Virginia.

Reference: Stephenson, J.W. Burning Wet Refuse. Proceedings and Discussions of ASME National Incinerator Conference, pp. 260-264, June 1972.

Abstract: A survey was conducted to investigate wet-refuse burning problems. The results from fifteen plants of different sizes, types, and ages are discussed in the paper. The main problems are: start-up, slow burning, and low heating value of refuse. The author concludes that preheated combustion air, automatic control of underfire and overfire air, auxiliary fuel burners, and grate operation are all necessary to burn wet refuse.

Reference: Storck, W.J. Sludge id Beautiful in the Twin Cities. Water and Wastes Engineering. 11,7:43-46, July 1974.

Abstract: Minneapolis/St. Paul is planning a sludge pyrolysis unit which will use municipal refuse as the source of fuel for the processing of sludge and for production of both fuel char and process char, which can be used in augmenting the overall treatment in sludge disposal systems. Pyrolysis will produce two important and useful products: off-gases that can be used as fuel to support the process; and a carbonaceous residue that can provide carbon suitable for fuel and/or activation, thus providing a source of absorptive media for use in wastewater purification. The process is described as mixing sludge and refuse, drying, and feeding the mixture to a rotary kiln. The kiln is externally heated by a furnace that burns the gaseous and liquid fuels derived from the pyrolysis off-gases. The mixed material is thoroughly agitated and exposed to a temperature of 680°C (1,250°F) for 30 to 60 minutes, driving off volatiles and leaving a char material consisting mainly of carbon and ash. The kiln off-gases are collected and processed in a gas-cleaning system that condenses the tar and oils. The remaining gas is suitable for fuel gas, having a heat value of approximately 4,000 kg-cal/st cu m (450 Btu/st cu ft). The tar and oils condensed from the pyrolysis off-gas stream are stored in tanks and burned within the plant. The char produced by the pyrolysis kiln is processed into three fractions: char suitable for processing into activated carbon; fuel-grade high ash char for delivery to the primary sludge incinerators; and a residue of inert ash to be disposed of in a landfill. The pyrolysis system includes equipment for sorting valuable materials from the refuse stream, including cellulose products, ferrous metals, glass, and aluminum.

Reference: Stovall, J.H. and Berry, D.A. Pressing and Incineration of Kraft Mill Primary Clarifier Sludge. TAPPI, 52,11, November 1969.

Abstract: The paper describes the disposal of sludge from the paper industry; dewatered sludge is mixed with bark and burned in hogged-fuel-fired boilers. These installations are at Mobile, Alabama; Georgetown, South Carolina; and Vicksburg, Mississippi.

Little data are presented on the co-incineration aspects of the operation, but at the Mobile Mill the sludge is dewatered in a vertical screw press to 30-35 percent solids, mixed with bark and burned in a small 45,500 kg (100,000 lb) per hour boiler. When burning bark and sludge, a 20 percent drop in steam flow is observed, although sludge feed rate is unknown.

Reference: Sumner, J. and D.H.A. Price. Combined Incineration of Refuse and Sludge. Proceedings of a Symposium at the University of Southampton, U.K., January 1972.

Abstract: The authors discuss the pros and cons of co-incineration. Included are the comments of attendees. The presentation and discussions are general, although the authors conclude that further experimental work is necessary and that co-incineration is likely to prove more economical than separate incineration methods.

Reference: Sussman, D.B. Baltimore Demonstrates Gas Pyrolysis-Resource Recovery from Solid Waste. U.S. EPA Report S.W.-75d.L. (1975).

Abstract: The prototype 909 metric ton/day (1,000-tpd) Monsanto "Landgard" pyrolysis plant in Baltimore, Maryland is described. The full-scale plant was based upon a 32 metric ton/day (35-tpd) plant operated in St. Louis by Monsanto. The pyrolyzer is a 5.8-m (19 ft) diameter by 30.5-m (100 ft) long rotary kiln. The pyrolysis gases are burned in an afterburner and pass through a waste heat boiler. The steam is exported for sale, and the residue is quenched with water. Sewage sludge was pyrolyzed successfully at the pilot plant, and co-incineration may be further demonstrated in the full-scale unit. The facility is in start-up and is scheduled to be turned over to the City in 1975.

Reference: Tanner, R. A Process of Incineration of Solid Waste, in Particular Refuse, and Hygienic Destruction of Sewage or Liquid Sewage Sludge and an Incineration Furnace for Carrying the Process into Effect. U.K. Patent No. 1,165,349, dated 24 September 1969.

Abstract: This patent describes a basic solid waste incinerator into which sewage sludge is sprayed to maintain a safe operating temperature and to dispose sewage sludge. The inventor notes that the feeding value of solid waste refuse has been steadily increasing from a historical value of 2,600-4,200 kg-cal/kg (1,440-2,340 Btu/lb) to a present range of 4,900-6,500 (2,700-3,600). This increase results from an improved standard of living and increased use of "disposables". Higher heating values have resulted in excessively high temperatures within the incinerator combustion zone, which have limited the capacity of existing incinerators. While excess air could be used to cool the combustion chamber, the existing units generally do not have the blower capacity or stack-gas cleaning capacity to reduce the temperature of the combustion chamber.

As a solution, the inventor suggests spraying raw sewage sludge, at 8 percent solids, into the combustion chamber over the burning refuse. Excessive heat is thereby consumed in the evaporation and superheating of the water in the sludge. At the same time, noxious sewage sludge is continually disposed. Available solid waste was estimated at 250 kg (550 lb) per person per year. At the same time, 350 kg (770 lb) of sewage sludge, at an 8 percent consistency (30 kg -- 66 lb -- of solid), are generated per person per year. Drying, evaporating, and superheating the water in the sludge to 300°C (570°F), 50-66 percent of the available heat output of the burning refuse is consumed. The raw sewage sludge is simply sprayed into the combustion chamber, above the burning refuse. The sludge may also be indirectly preheated by combustion gases before being sprayed into the incinerator. A waste heat boiler can also be used to recover some of the heating value of the refuse. In this case, the quantity of sludge to be dried would be reduced to the point of safe operating temperature in the incinerator.

Notes: The thrust of this patent is the control of temperature in the incinerator, rather than the disposal of sewage sludge. Water could more conveniently be used for the same purpose.

Reference: Tanner, R. Process and Mechanical Equipment for the Concomitant Incineration of Solid Refuse and Aqueous Sewage Sludge. U.S. Patent No. 3,529,558 dated September 22, 1970.

Abstract: The inventor proposes a means of pretreating sewage plant sludge for ultimate co-incineration with solid waste. Heat requirements for pretreatment are supplied by the heat of the combustion.

Tanner reports available solid refuse in the range of 0.7-2.0 kg (1.5-4.4 lb) per person per day. This waste would contain approximately 30 percent non-combustibles, 30 percent water, and 40 percent combustible materials. Combustibles would have a heating value of about 13,000 kg-cal/kg (7,200 Btu/lb) bringing the overall heating value of the solid waste to 45,000 kg-cal/kg (2,500 Btu/lb).

Sewage sludge was estimated at one to two kg (2.2-4.4 lb) per person per day, with a solids content of 8 percent. Half the sludge solids are combustible, with a heating value of about 13,000 kg-cal/kg (7,200 Btu/lb).

In the process described, solid waste is burned in a typical incinerator. The combustion gases are used to indirectly heat the sewage sludge, concentrating it from a consistency of 8 to 15 percent solids. The thickened sludge can then be sprayed into the solid waste incinerator and burned. The vapor from the evaporator is combined with hot gases from the incinerator to destroy any odorous material.

Alternatively, the evaporator could be of a pressure type. If the sludge is evaporated at the temperature of 150°C (300°F) or higher (about 5.9 bar -- 85 psi), a conditioning takes place which permits further mechanical dewatering of the sludge. The inventor reports that 15 percent sludge from the pressure evaporator can be thickened to 30 percent in a centrifuge or 50-55 percent in a pressure filter. The semi-solid thus formed is combined with the solid waste and burned in the incinerator. The liquid from the mechanical dewatering step, containing noxious material, is then eliminated by spraying it into the hot exhaust gases from the incinerator.

Notes: The secondary dewatering, after high temperature treatment, may be a useful concept if a satisfactory means of liquor disposal can be found. Fouling in the evaporator may be a serious problem. Spraying 15 percent consistency sludge into an incinerator also seems questionable.

Reference: Tanner, R. Method and Combined Furnace for the Simultaneous Incineration of refuse or Garbage and Sewage Sludge. U.S Patent No. 3,533,305 dated October 13, 1970.

Abstract: This patent describes a two-zone incinerator for the combined drying and incineration of solid waste and pre-conditioned sewage sludge cakes.

In the proposed incinerator, solid waste is burned in a two-zone, traveling grate. Solid waste is deposited on the first grate, where it is dried and ignited. The burning waste then drops to a second grate, where combustion is completed. Combustion air is provided by underdraft.

Sewage sludge is dried in the second zone of the incinerator, above the solid waste combustion zone. Pre-conditioned sludge with a moisture content of 40-50 percent is spread, at a controlled thickness, onto a moving grate. A portion of the hot combustion gases is forced through the grate, thereby drying the sludge to a mositure content of 20 percent. The dried sludge moves to the second grate, where it is ignited and burned. Hot air (unspecified source) is supplied underdraft.

At the end of the second sludge grate, the residue drops onto the center of the second solid waste combustion grate, where any remaining combustible materials are consumed. Hot combustion gases from the burning solid waste pass over the burning sewage sludge, further heating the sludge and promoting the combustion. Vapors from sludge drying are also combined with the hot combustion gases, and any noxious materials are destroyed.

Notes: Use is highly limited, due to the need for very high consistency sludge.

References: Tanner, R. and W. Vrenegoor. Sludge and Liquid Wastes Disposal for Combined Incineration Systems. Solid Waste Management and Disposal. The International Edition of 1971 Australian Waste Disposal Conference, University of New South Wales, pp. 105-108.

Abstract: The von Roll, S.A., Switzerland personnel presented the paper, which describes use of a special high-speed evaporator to concentrate the sludge solids from 95 percent to 40-45 percent moisture content. The dried sludge is then metered into the feed hopper of a MMR incinerator and burned on a grate system. Steam for the evaporator may be supplied by a steam-generating incinerator.

References: Tanner, R. Gemeinsame Verbrennung von Müll and Klärschlamm mit Abwärmeverwertung zur Schlammtrocknung (Combined Refuse and Sewage Sludge Incineration with Waste Heat Utilization for Sludge Drying). VGB Kraftwerkstechnik, 52,2:140-145, April 1972.

Abstract: The von Roll indirect sludge drying system, which will be installed at Dieppe, France, has a steam-generating, grate-fired incinerator, where the dried sludge is metered into the furnace charging hopper. The vapors from the evaporator are ducted to the furnace, and the system is recommended for sludge quantities of less than 50 liters/hr (13.2 gph).

Reference: Taylor, R. Combined Incineration of Refuse and Sludge. Environmental Pollution Management. 3,2:89-94, March/April 1973.

Abstract: The paper discusses three methods of burning sludge with refuse: 1) direct addition of dewatered sludge into the furnace using mechanical dispersion (rotating brush or impeller or a secondary pressurized fluid, such as compressed air or steam; 2) direct gas-phase contact with the products of combustion; and 3) indirect drying using an intermediate heat transfer fluid such as steam.

The recommended system is indirect drying using steam in a special (von Roll) thin-film evaporator fitted with a rotor and scraping blades to keep the heat transfer surfaces clean. A full-scale plant is operating in Dieppe, France. The vapors and incondensible gases from the evaporator are ducted into the furnace and heated to 750°C (1,380°F) to prevent odor emissions from the raw refuse incineration plant.

Reference: Thompson, L.H. Sludge Treatment and Disposal - GLC Experience and Investigations in the Field of Sludge Disposal. (Presented at the Fourth Public Engineering Conference, Lanhborough University of Technology, 1971.

Abstract: The following is quoted from the paper:

"**Incineration with Refuse**

It will be realized that the Council is responsible not only main drainage and sewage disposal (or treatment as we now to our operations in this field) but also for refuse disposal. It is therefore convenient to consider where, if at all, these functions may overlap and facilities or processes complement each other. For example, it has been simple and mutually beneficial to both of these sections of the waste disposal service, for sludge to be used as a top dressing to reinstated tips, accelerating the growth of luxuriant herbage and providing a cheap, useful method of disposal for the sludge.

"Similarly, as the increasing shortage of refuse tips within economic reach of London drives the Council deeper into a policy of refuse incineration, it has been possible, indeed logical, to ask: Can the (waste) heat derived from burning refuse be used to evaporate the unwanted water from digested sewage sludge? Both the waste heat and the water tend to be problems, so why not bring them both together to eliminate each other.

"In August 1969 a Working Party under the Chairmanship of the Council's Scientific Advisor, with representatives of the Sewage Treatment and Refuse Disposal Branches and the Mechanical and Electrical Department was set up by the Director of Public Health Engineering to investigate the possibilities of joint incineration. At the time of writing, the Working Party has not yet reported although at least an interim report is imminent.

"Several specialist firms, in this country and abroad, have been consulted and installations inspected. Two schemes are considered worthy, in the author's opinion, of further (pilot scale) investigation and development. The flexible methods, which may allow the heat from the separate incineration of the refuse to be used for driving off the water from the sludge, to whatever water-content is desired, are particularly attractive. The sludge could then be either fully incinerated or withdrawn for utilization on land in a dry sterilized state, as demand may dictate. These two methods are: 1) drum-drying, which has been used, and is currently being further installed, at several plants in Sweden; and 2) multiple evaporation, which is in a relatively early stage of development (in Germany) so far as sludge is concerned, but which is a well estabsihed method for desalination and other purposes.

"At a plant near Stockholm 800 metric ton/day (880 tpd) of refuse has been burnt in an incinerator intended to serve 2 drum-dryers, each of which was intended to dewater 216 metric ton/day (238 tpd) of digested sludge. However, because the exhaust gases from the refuse incinerator could not be maintained at the design figure of 900°C (1,650°F) it has been found necessary to burn oil in the drum-dryers at a rate of 800 litres per 9 metric tons of wet sludge (211 gal/9.9 tons) - at 95 percent water content.

"It would not appear to be an impossible task to design and construct a refuse incinerator from which exhaust gases at 900°C (1,650°F) could be consistently obtained. In which case, the drum-dryer seems to be a flexible, and perhaps a not unduly expensive tool with which to reduce the water content of sludge over a wide range. The final product seen in Sweden resembled Morganic - as produced at Mogden.

"The multiple evaporation experimental plant is said to have run for 1,800 hours at Hamburg but until at least a pilot scale unit had demonstrated its ability to run on British sludge without caking of the coils and consequently a serious reduction of heat transfer, a major installation would not be recommended.

"Other methods of sludge incineration where wet sludge is mixed with the refuse or sprayed into the combustion chamber do not appear to be capable of dealing in practice with anything approaching the quantity of water which theoretical calculations indicate should be possible. Seldom has it been demonstrated that 1 kg of refuse will evaporate more than 1 kg of water. Consequently, if both sludge and refuse are derived from the same catchment area, either the sludge has to be dewatered to some extent prior to joint incineration or one must accept that only a proportion of the sludge can be dealt with in this way. Either way, costs are increased. Furthermore, to burn refuse in multiple hearth or fluidized bed furnaces it is first necessary to mill the refuse--another additional cost.

"The destruction of organic matter which is potentially useful must be questionable and it is therefore suggested that further development of methods for the drying of sludge using refuse incineration is preferable to complete joint incineration.

"This appears to be a suitable point to consider further the basic choice, which seems to be arising with increasingly important conservationist connotations."

Reference: Wallace, J.A. Incineration of Refuse in Hong Kong. Proceedings of ASME National Incinerator Conference (1974).

Abstract: The author discusses Hong Kong's experience in dealling with high-moisture-content refuse. Most of their systems have been Volund, where a drying grate feeds a burning grate and combustion is completed in a short rotary kiln. Based on their experience with these Volund units, they state:

"The wide and frequent rapid variations in the moisture content have resulting in fluctuations in the time required for drying and combustion, the net effect being substandard burnout unless the charging rate can be corrected in time to compensate for such fluctuations. It is evident that the concept of drying by radiation and convection from the flame is only partially effective, for little more than the top layers of the refuse bed receive treatment and, under some conditions, the under layers may still be high in moisture content upon the burning grate prior to the kiln. Thus even with reciprocating grate, distrubance and turn over of the under layers are difficult when dealing with refuse containing a high moisture content.

"A further very noticeable effect is the retardation of both drying and the combustion of released volatiles above the bed when large quantities of moisture vapor are contained within the combustion chamber.

From these observations, it was concluded that it was essential in the incineration of Hong Kong refuse to incorporate in any new plants, effective and flexible means of pre-drying, such treatment taking place in a chamber independent of the combustion chamber proper."

They further state that: "The rotary kiln provided on the existing plants has proved eminently suitable for this prupose by virtue of the available variation in speed and consequent variation of residence time in the final burnout stages. It was decided, therefore, that on future plants the overall combustion rating should be decreased on the rotary kiln should be incorporated unless it could be shown that equal flexibility was obtainable by other means."

The rating was thus to be based on 215 kg/sq m-hr (44 lbs/sq ft-hr), based upon the effective grate area and the outline of the proposed plant. Note that drying of the wet refuse is accomplished on a separate grate system using hot flue gases as the drying medium. This practice of ventilation-drying is based on Japanese practice, and the authors further state that the choice of flue gas as the drying medium was made for the following reasons:

"(a) It minimizes the burning of easily combustible materials during the drying process by retardation of ignition so that the maximum heating value of the refuse is retained for the combustion process within the combustion chamber.

"(b) More drying heat can be applied than with hot air as higher temperatures can be obtained.

"(c) The specific heat of flue gas with its higher moisture content is higher than that of air.

"The advantage in using recirculated flue gas is however slightly affected by the fact that the grate materials and supporting framework have to be constructed from materials capable of withstanding possible corrosion and deformation.

"Sufficient moisture will be removed in the drying process to ensure that, upon discharge from the drying grate, the refuse will be in a self supporting condition from a combustion aspect irrespective of the condition at entry."

Reference: Watson, R.H., and J.M. Burnett. Recent Developments and Operating Experience with British Incinerator Plant. Proceedings and Discussions of ASME National Incinerator Conference (1972).

Abstract: The authors comment on co-incineration as follows:

"The costs involved in conventional dewatering of sludge to make it autothermic, or the expense of supplementary fuel, and the difficulties in achieving satisfactory burnout have led to much thought on combined refuse and sludge incineration. Trials have been made both on standard refuse plants accepting sludge cake or sprayed sludge and on special purpose furnaces. Two points on which there is yet no general agreement are the temperature to which the gases from the sludge must be heated and the period of time for which the temperature must be held, to avoid offensive smells at the exhaust.

"The first combined sludge/refuse plant has recently been ordered and is intended to accept sludge at 4 percent solids with provision for supplementary firing of gas oil."

__Reference__: Wegman, L.S. A Single Project for Refuse Incineration Sewage Treatment and Steam Generation. Paper No. 68-162, APCA Annual Meeting, St. Paul, Minnesota, June 1968.

__Abstract__: The only information pertinent to co-incineration is:

> "Sludge disposal via mixing in a refuse furnace is more likely. Sewage sludge moisture content ranges from 97 percent, or higher, for a raw primary sludge down to about 75 percent for a thickened and filtered sludge. At the 75 percent content, the daily yield from 1,000,000 persons is 272 metric tons (300 tons) a sizeable fraction of the 2,045 metric tons (2,250 tons) of refuse. Some preheating will be needed but any odor emission can be readily handled--which previously deterred this process. And adequate heat should not be a problem."

__Reference__: Weyrauch, H. Die Karnaper Verfahren als Beitrag zur Veroschung von Siedlungs -- und Industrieabfallen (The Karnap Procedure for the Reduction of Settled Solids and Industrial Wastes). (Presented at the Second International Congress of the Internation Society for Refuse Research Concerning Removal and Disposal of Settled Solids and Industrial Wastes, 22 to 25 May 1962 in Essen, West Germany)

__Abstract__: The paper describes a conceptual furnace design based on experience in burning shredded refuse or dried sludge in pulverized-coal-fired furnaces. Included is a hammer mill modified to operate as a hot flue gas-swept sludge dryer discharging to the furnace, where the dried sludge burned in suspension. Raw refuse burns on the grate system, and the auxiliary fuel is pulverized coal.

__Reference__: Zack, S.I. Sludge Dewatering and Disposal. Sewage and Industrial Waste 22,8:975-996, August 1950.

__Abstract__: This paper identifies some of the plants reportedly burning sludge with refuse. These plants are:

1. Frederick, Maryland (Mixed with MMR)
2. Bradford, Pennsylvania (Proposed) (Flash Dryer)
3. Bloomsburg, Pennsylvania (Proposed) (Flash Dryer)
4. Stamford, Connecticut (Flash Dryer)
5. Tenafly, New Jersey (Flash Dryer)

6. Lansing, Michigan (Multiple Hearth)
7. Lederle Laboratories, Pearl River, New Jersey

At Frederick, the undigested primary sludge is dewatered by vacuum filter to 30 percent solids, mixed with refuse and burned in a MMR incinerator. The ratio of wet refuse to wet filter cake is 2.9:1. The Bradford and Bloomsburg plants were not operating at the time of the report.

Little information is provided for the Stamford and Tenafly installations, but it is stated that the flash-dried sludge is incinerated in refuse incinerators.

Lansing reportedly digests ground garbage with activated sludge, and the vacuum-filter-dewatered mixture is then burned in a multiple-hearth furnace.

Lederle Laboratories is reported to have a mechanically-stoked refuse incinerator with an auxiliary sludge-drying hearth burning rubbish, sewage sludge, and spent laboratory media.

Attempts at burning liquid sludge without dewatering in a multiple-hearth incinerator at Piqua, Ohio, required 88 gal/ton (3031/metric ton) -- oil/dry solids.

APPENDIX B

PLANT VISITS

VISIT TO THE ALTRINCHAM INCINERATOR, GREATER MANCHESTER METROPOLITAN CITY COUNCIL, MANCHESTER (CHESHIRE COUNTY), ENGLAND, 19 SEPTEMBER 1974

The principal contact was Mr. Davidson, the Waste Disposal Officer for the Greater Manchester Council, which had recently taken over responsibility for the plant (an administrative and financial consolidation of waste management responsibilities within the Counties now taking place over all of England). Mr. Davidson's offices were located at the County Engineering Department, County Hall, Piccadilly Gardens, Portland Street, Manchester, England.

The Altrincham plant consists of two furnaces, each having sections of rocking grates, fed by a conventional pit and crane. As long as the plant has been in operation (approximately a year), the refuse has, unaccountably, been consistently damp and occasionally very wet. The low calorific value and the operating problems discussed in the following paragraphs have made co-firing of sludge almost impossible.

The sludge is fed to the furnace in a jet from the wall at the discharge end of the furnace. In order to project the sludge stream over the residue quench tank into the hotter parts of the furnace, a relatively small (perhaps 1 cm) pipe is appropriate. However, it has been recommended (and shown prudent) that a 7.6-cm (3") diameter pipe be used in order to avoid plugging problems with hair and other debris in the sludge. This rather obvious conflict has made sludge firing impractical. The small diameter pipe (about 2 cm) used suffers repeated plugging. Compounded by other operating problems (discussed later) and the high moisture content of the incoming refuse, co-firing has been indefinitely discontinued.

The sludge is received at the plant in tank trucks from a nearby treatment plant and stored in a large, rectangular concrete tank located under the ramp leading up to the tipping area. The tank was not provided with an agitator, and when high-water-content sludges were placed in the tank, they settled out rapidly, making for difficult pumping and variable moisture content. A jerry-rigged agitator was installed in the tank, but did not effectively maintain homogeneous sludge. Also, odor problems occurred when the open sludge tank (which was not aerated to maintain aerobic conditions) went septic. Sludge is pumped from the storage tank into the plant, where a 4 to 8 cu m (1,000-2,000 gal) run tank is located. A second pump moves the sludge from the run tank to the atomization point, with a return pipe to the hold tank.

In general, the plant operator was quite disenchanted with co-firing, and felt that there was no good way to carry out the operation with the Altrincham equipment. With only two grate sections, the burnout was already bad, and adding wet sludge on top of the wet refuse tends to make the problem worse.

VISIT TO ANSONIA INCINERATOR, INCINERATOR/WASTEWATER TREATMENT PLANT, ANSONIA, CONNECTICUT

February 13, 1975 was the date of the visit to the Department of Public Works, Ansonia, Connecticut, to inspect the incinerator and sludge dryer facilities.

Ansonia is a small community of about 20,000 people. The residents are served by an integrated wastewater treatment plant and municipal refuse incinerator. Approximately half the sludge from the water treatment plant is dried in a Nichols Spray Dryer, using off-gas from the incinerator.

Incinerator

Ansonia's Incinerator Plant consists of two rocking-grate, continuously stoked incinerators with a combined capacity of 190 metric tons (200 tons) per day (24 hours). The plant operates on an 8-hour day, 5-day per week schedule, burning about 50 metric tons (55 tons) per day of refuse. This represents about 70 percent of Ansonia's solid refuse load. The remaining 30 percent, consisting mostly of bulky refuse, is landfilled. Very little landfill area remains in Ansonia, and a shredder has been installed (but is not yet operational) at the plant to permit incineration of a greater portion of the town's refuse.

Refuse is continually charged to the incinerator. Combustion air is supplied both under and over the grate; air is also used to cool the combustion chamber walls. Ashes are quenched and landfilled. Combustion gases from the two units are combined in a "secondary combustion chamber" before scrubbing in a Detrick-Jens Scrubber, operating at a pressure drop of about 1" W.G. An induced draft fan discharges the scrubbed gases to the stack.

Wastewater Treatment Plant

The Ansonia Treatment Plant handles all domestic and light industrial wastewater, with both primary and secondary treatment. Incoming water is degritted and settled, and the overflow is treated in an activated sludge aeration pond. The treated water is again settled, and the overflow is chlorinated and discharged to the Naugatuck River. Excess secondary sludge is returned to the primary settling tank. Sludge from the primary settling tank is about 50:50 primary/secondary.

The sludge is thickened to a consistency of about 4 percent. Thickener overflow returns to the primary settling tank. About half the thickened sludge is pumped to the incinerator for drying and ultimate use as a fertilizer. The remainder goes to anaerobic digestion. Digester gases, about 510 cu m (18,000 cu ft) per day, are burned at the digester to maintain sludge temperature of 50° (120°F). Digested sludge is then sent to drying beds. Drying of digested sludge is very inefficient -- there is virtually no percolation. Sludge lagoons are being constructed to take excess sludge from the water treatment plant. Figure B-1 is a simplified flow diagram of the wastewater treatment system.

Sludge Drying and Co-Incineration

The 4 percent sludge is held in an air-agitated tank before drying in a Nichols Spray Dryer. Feed to the dryer is from a variable-speed Moyno Pump. A high-speed disc atomizes the sludge in the co-current dryer. Inlet temperature is about 650°C (1,200°F) and outlet temperature is 150°C (300°F). Outlet temperature controls the speed of the sludge feed pumps.

Heat input to the spray dryer is furnished by diverting a small portion of the incinerator combustion gases (hot gases drawn from a "secondary combustion chamber" just before the scrubber). Temperature at this point generally was lower than expected, partially because of turbulence caused by the draft control vent. The spray dryer was not able to operate at design rate, requiring that half the water treatment plant sludge be diverted to the digesters. The incinerator is being modified to permit take-off to the spray dryer directly from the incinerator combustion chamber. Gas temperature at this point is expected to be 980°C (1,800°F), thus significantly increasing the capacity of the spray dryer.

Dried sludge solids are brought out in the cone of the dryer or in the off-gas cyclone. Sludge moisture content at this point should hold 15 percent less, to eliminate build-up on the dryer walls. Pneumatic conveying equipment is available to return the dried sludge solids to the incinerator, where they burn in suspension above the second grate; however, Ansonia generally does not burn the sludge. Local residents or the State Highway Department use most of the sludge solids as a fertilizer. Figure B-2 is a cross-section of the incinerator.

VISIT TO BÜLACH UNIT, BÜLACH, SWITZERLAND

Upon arrival in Europe, it was learned that the Bülach Unit in Switzerland was shut down. This was verified in Zurich. There was some talk about explosions and repair problems at this plant. Mr. Helle, of Lurgi in Frankfort, advised contact with Mr. Van Der Kraan in Dordrecht, Holland, and to visit the plant in that city.

VISIT TO DIEPPE INCINERATOR, WASTEWATER PLANT/INCINERATOR, DIEPPE, FRANCE

The incinerator and wastewater treatment plant at Dieppe, France was visited on May 16, 1975. The plant is about 3 1/2 years old. M. Jean Fossey is in charge of the plant, as Chef d' Exploitation.

Solid waste is delivered to the plant from Dieppe and the surrounding area by truck, from a population of about 60,000 and from industrial sources.

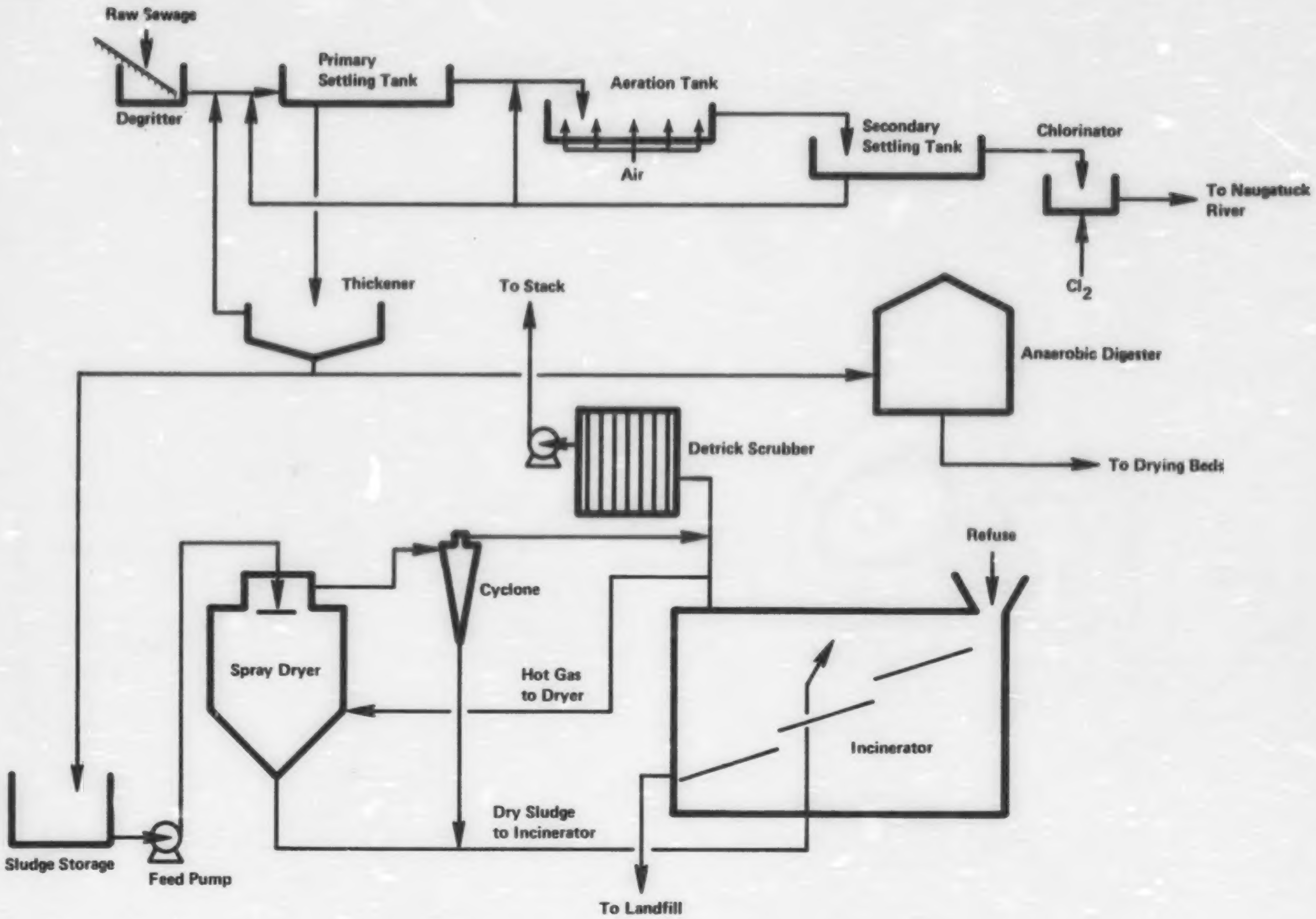

Raw Sewage
Degritter
Primary Settling Tank
Aeration Tank
Air
Secondary Settling Tank
Chlorinator
To Naugatuck River
Cl2
Thickener
To Stack
Anaerobic Digester
Detrick Scrubber
To Drying Beds
Refuse
Cyclone
Spray Dryer
Hot Gas to Dryer
Incinerator
Dry Sludge to Incinerator
Sludge Storage
Feed Pump
To Landfill

Figure B-1. Water Treatment and Incinerator Flow Sheet, Ansonia, Connecticut.

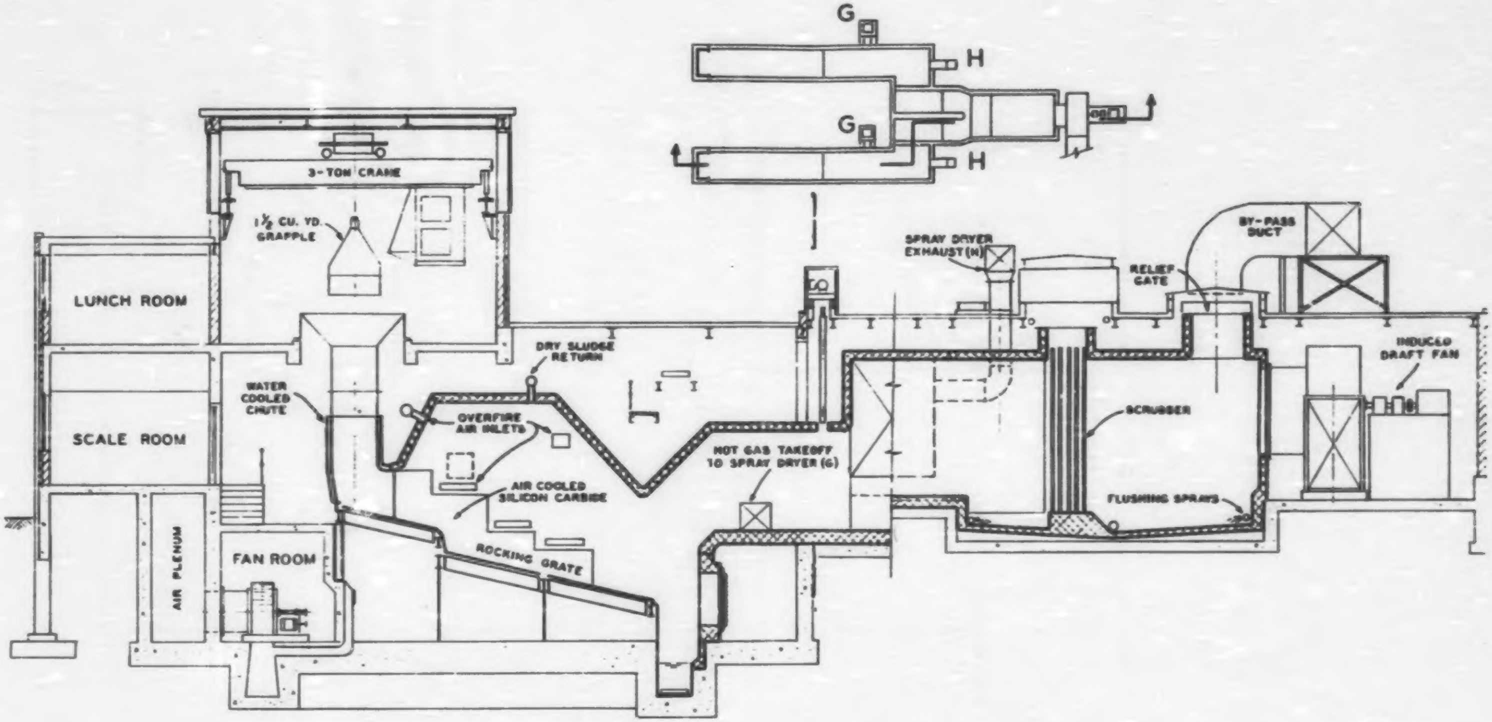

G
H
G
H
3-TON CRANE
1½ CU. YD. GRAPPLE
LUNCH ROOM
SCALE ROOM
AIR PLENUM
FAN ROOM
WATER COOLED CHUTE
DRY SLUDGE RETURN
OVERFIRE AIR INLETS
AIR COOLED SILICON CARBIDE
ROCKING GRATE
HOT GAS TAKEOFF TO SPRAY DRYER (G)
SPRAY DRYER EXHAUST (H)
RELIEF GATE
BY-PASS DUCT
SCRUBBER
FLUSHING SPRAYS
INDUCED DRAFT FAN

Figure B-2. Longitudinal Section Through Incinerator, Ansonia, Connecticut.

The incinerator plant consists of two von Roll incinerators with reciprocating grates and with an average capacity of 2.5 metric tons (2.75 tons) per hour, or 60 metric tons (66 tons) per day, each. Operation is 5 days per week, 24 hours per day. The maximum capacity of each furnace is 70 metric tons (77 tons) per day.

The sludge that is co-incinerated in the plant comes from the sewage treatment plant on the same grounds, sized to accommodate the flow of 40,000 inhabitants (equivalent with a theoretical daily flow of 81 cubic meters (21,000 gpd) and an average BOD_5 loading of 250 mg/liter.

Municipal Sewage Treatment Plant

The biological wastewater treatment plant consists of a primary clarifier, aeration basin, and secondary clarifier. Secondary sludge is recycled to the primary clarifier, where both primary and secondary sludge, as well as skimmings, are removed. This sludge also contains sand, grit, etc. (Because of the large amount of shellfish consumed in this fishing town, large amounts of sand and shell parts are contained in the influent.) The primary and secondary sludge, together with skimmings, are then pumped to the anaerobic digesters, from which the digested sludge is transferred to the thickener by way of a comminutor.

The thickened 4 percent digested sludge is then passed through a delumper (macerateur) and is pumped to the day tank in the incinerator plant. Digester gas is used to heat the digesters and the plant control building.

Incinerator Plant

A recirculating pump has been added to the sludge day tank to eliminate plugging problems resulting from settling of solids. M. Fossey is looking into the use of a rubber-vane pump, because standard centrifugal pumps are subject to wear and clogging. The sludge piping is flushed with water each shutdown, to prevent clogging.

The sludge is fed to the vertical thin-film evaporators by screw pumps. These pumps are subject to considerable wear; the stator wears out in about 6 months, and the impeller lasts about a year. This wear is thought to be caused by waste from shellfish. The pump capacity varies from the 750 l/hr (200 gph) design flow to about 1,200 l/hr (320 gph) after excessive wear. As the capacity reaches 1,000 l/hr (260 gph), because of wear, the internals usually have to be replaced, because the evaporator discharge then becomes too wet (more than 60 percent moisture content) for proper incineration.

The two thin-film evaporators are Luwa Double-Wall Dryers operated on 10 kg/sq cm (140 psi) steam at about 180°C (355°F). The evaporators are vertical with top inlet and bottom outlet.

The feed to the dryers consists of 4 percent solids sludge, and the discharge has an average consistency of 52 to 55 percent dry solids. The solids discharge is sometimes very uniform and granular in appearance, but at other times it is very irregular, and big lumps, 10 to 30 kg (22-66 lb), drop out of the discharge.

The dryers discharge onto a Luwa discharge conveyer belt, which transports the dried sludge to chutes for discharge into the incinerator feed hoppers. These batch-feed chutes are kept full with about 500 kg (1,100 lb) of solid waste from the pits. From 400 to 500 kg (880-1,000 lb) of waste are placed in a hopper, and the hopper is always kept full. The dried sludge is continuously fed into the hoppers, but refuse is charged only as the hopper is emptied. There is no danger from overflowing of the hoppers, because they have large excess capacity and are continuously monitored by remote T.V. from the control room. The feed hopper is equipped with hydraulically operated flaps that batch-feed the furnace.

The evaporator vapors pass through a demister before flowing through a heat exchanger (added after construction had been completed). The vapors from the dryer were originally fed into the hottest zone of the furnace, but now the vapors are fed into the undergrate hopper, in the burnout zone (not the drying grate). These changes were made to the original installation because problems were encountered with the waste-heat steam generator tubes. Excessive fouling of the tubes was thought to be caused by combustion gas condensation on the tubes. As already stated, a heat exchanger was moved from the combustion chamber to the hopper under Zone 2 of the von Roll reciprocating grates. Relocation of this discharge to the drop-section between the combustion and ash burn-out grates is still being contemplated.

The solid waste consists of about 85 percent municipal refuse and about 15 percent commercial and industrial solid waste. Large items are removed from the pits and landfilled. Automobile tires are burned at a maximum rate of 5 per day; truck tires are not accepted. Grits and screenings are burned as is secondary sludge; tertiary sludge is available, and chemical sludges are handled. The light-off burner, with oil and gas connections, has never been used.

Miscellaneous Data

For 1974 the following data are available:

17,062 metric tons	85 percent Municipal Refuse + 15 percent Industrial
2,123 metric tons	Sludge (based on dry solids) processed.
19,185 metric tons	Total incinerated
7,356 metric tons	of residue, with 60 percent water content, remained.

Reinterpreted, these data indicate a capacity of approximately 2.277 metric tons/hour (2.51 tph), which was low because of the problems encountered; the rate for 1973 was 2.846 metric tons/hour (3.137 tph). The capacity of the furnaces is 2.5 metric tons/hour (2.75 tph) design, with a maximum possible rate of 3.0 metric tons/hour (3.3 tph). One furnace is usually on stream, with the other down for maintenance or available for back-up capacity.

The waste heat boiler produces 7.5 metric tons (8.3 tons) of steam per hour at a pressure of 13 kg/sq cm (185 psi) when the design waste throughput rate is maintained. There is not enough demand to use all the steam. One Luwa dryer uses 1,500 kg (3,300 lb) per hour, and usually only one is used; but even if two are running, which does occur occasionally, the demand is only 3,000 kg (6,600 lb) per hour, and there still is surplus steam. The plant personnel, however, have added some other equipment to utilize this steam, including preheating of combustion air and heating of the vapors that come off the sludge dryers. The remaining excess steam, generated by the waste heat boiler, is condensed in a heat exchanger that is cooled by river water.

Sludge-to-refuse ratio is as follows:

Refuse: 2.5 metric tons/hour x 24 = 60 metric tons per day (66 tpd)

Sludge: 20 cu m/hr x 45 percent water = 23 metric tons per day (25 tpd)

Total Processed_ 83 metric tons per day (91 tpd)

55 percent Solids Sludge/Solid Refuse = 23/83 = 30 percent

Gases from the anaerobic digester have not been burned in the furnace. The fuel oil nozzle is not used at all in running or starting the incineration process.

This plant has never added water in the combustion chamber, either through the nozzle that has been provided or in any other fashion, for fear of waste heater problems and also, perhaps, to avoid refractory deterioration. An improved design has been suggested by M. Fossey to facilitate cleaning of the heater tubes and removal of the dirt that is released in a rather inaccessible space.

The air pollution control method here consists of multi-clones, a number of cyclones with a diameter of about 30 cm (12 in.). Some problems have been encountered in the past when trying to clean these cyclones. Originally, a solution was used to spray through these units, but this resulted in deterioration of many of the walls; now, all of these are mechanically cleaned with better success.

The plant is located some distance from population in an industrial park, and no odor problems have been encountered. Note that the pit is ventilated by the incinerator forced draft fan, as shown in the flow sheet and dryer diagram (Figures B-3 and B-4).

VISIT TO DORDRECHT PLANT (LURGI SYSTEM), DORDRECHT, NETHERLANDS

This report contains information gathered during the plant visit to "Gevudo" (Gemeenschappelijke Vuilverbranding Dordrecht En Omgeving) in Dordrecht. Mr. J.M. Van Der Kraan is in charge of the sewage treatment plant and the incinerator installation.

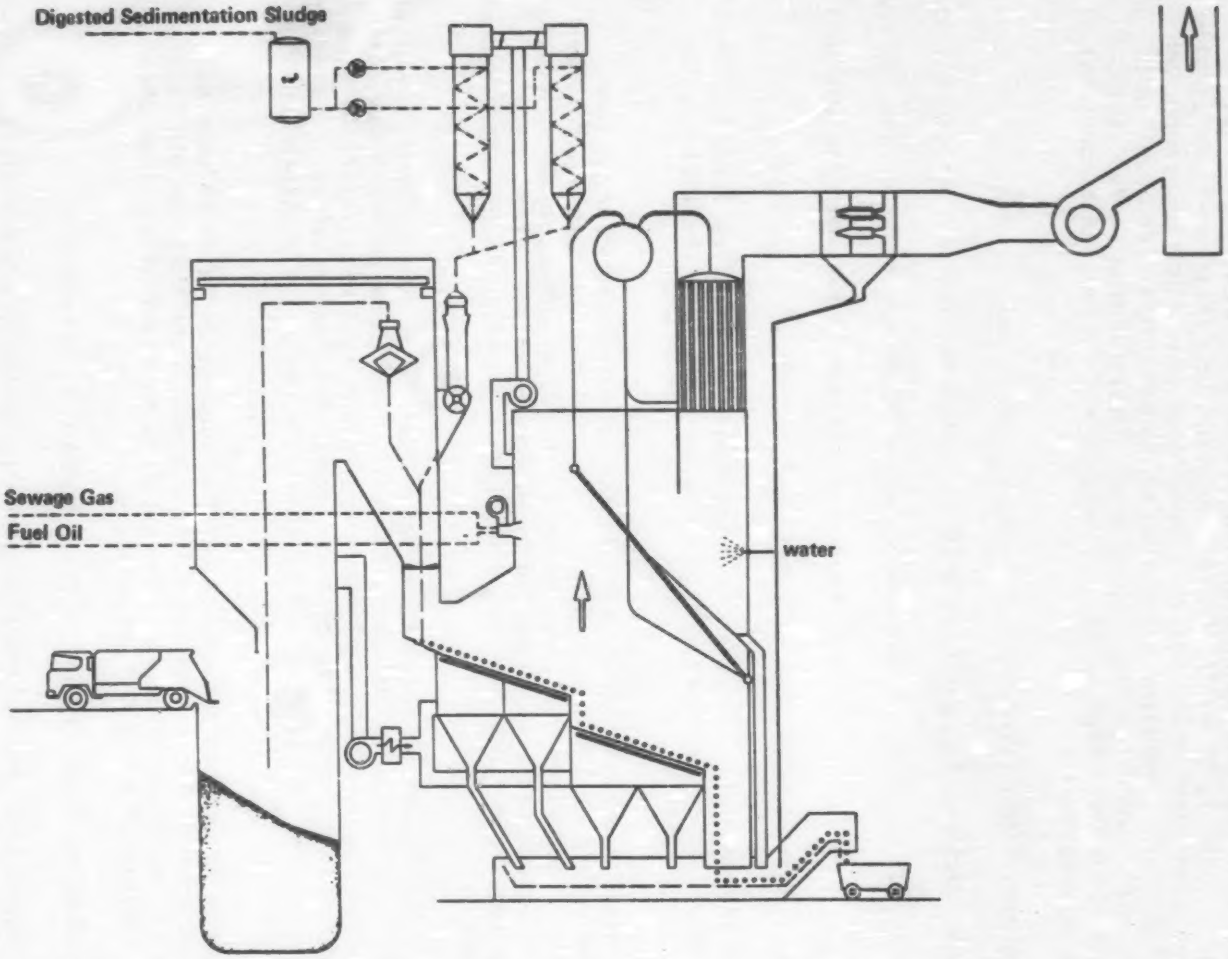

Digested Sedimentation Sludge
Sewage Gas
Fuel Oil
water

Figure B-3. Flow Sheet of Sewage Sludge and Refuse Incinerating Plant, Dieppe, France.

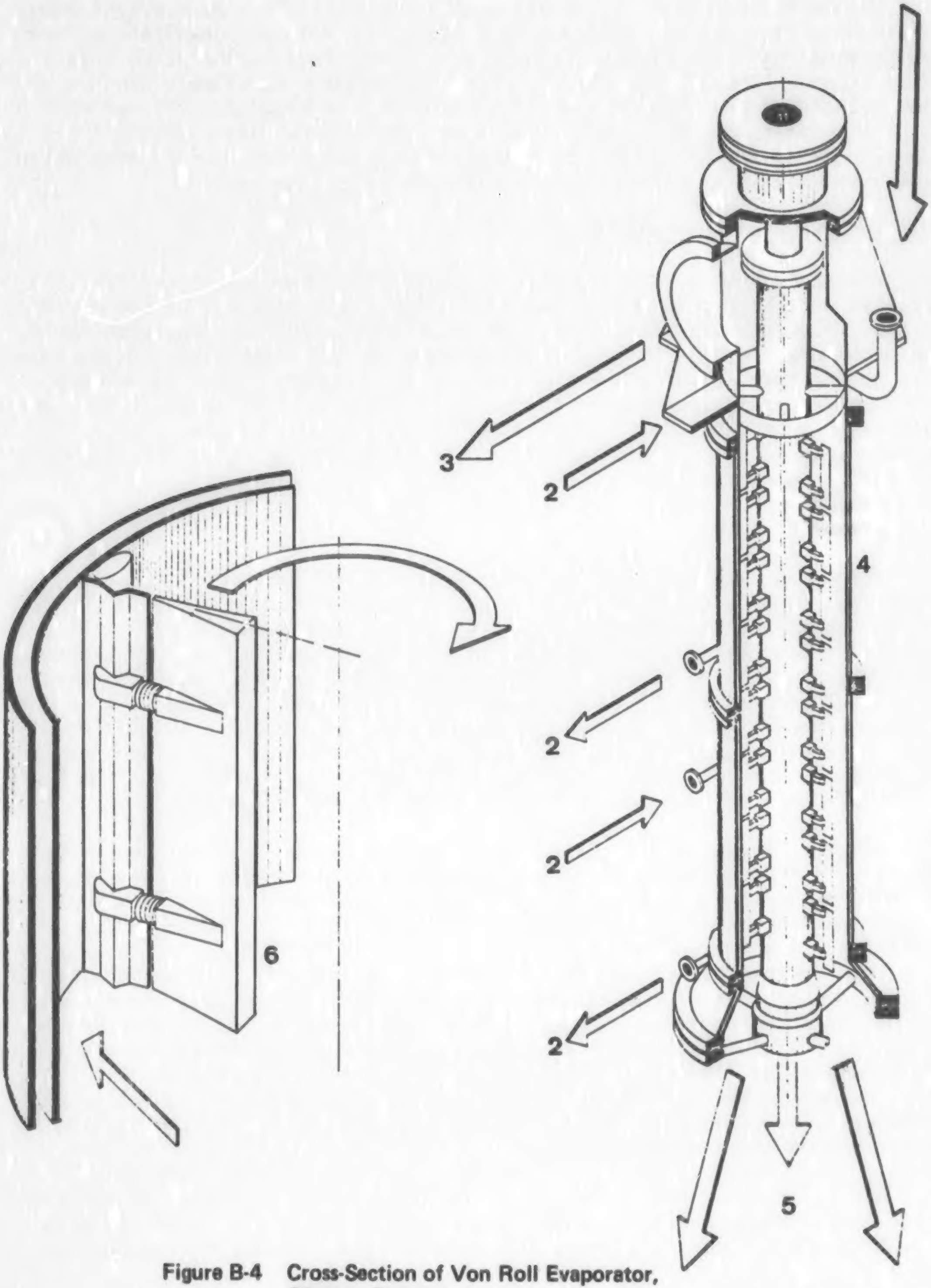


Figure B-4 Cross-Section of Von Roll Evaporator, Dieppe, France.

The Dordrecht Plant (2 1/2 years old) consists of: two parallel sewage treatment plant systems, each with a capacity of 100,000 inhabitant equivalents; three Martin-designed reciprocating grate-type incinerators with a capacity of 6.4 metric tons/hr (7 tph) each; and one Lurgi multiple-hearth sludge incinerator. The refuse incinerator serves 43 municipalities with a total population of about 360,000. Energy reclamation was rejected for this plant, because the nature of the operation would involve energy costs which exceed those of conventionally generated electrical power.

Municipal Sewage Treatment Plant

The sewer system in Dordrecht is subject to ground-water infiltration and also acts as storm sewer. The wastewater plant consists of two parallel systems, each consisting of a degritter, primary clarifier, aeration basin, and secondary clarifiers. Sludge from the secondary clarifiers is discharged into the primary clarifiers; the primary and secondary sludge (2 percent solids) are then pumped to the thickener. The thickened sludge (6 to 7 percent solids) is pumped to the incinerator building for centrifuging. Grit and skimmings are collected and burned in the refuse incinerator. No digesters are used in this installation.

Incinerator Plant

Refuse is received by truck from municipal (91.5 percent) and from industrial (8.5 percent) sources. The solid waste is dumped into a 300-cu m (10,600 cu ft) pit; oversize material is dumped in a separate pit. The oversize items are then reduced by means of the hydraulically operated Lindemann Shear. Two bridge-cranes with 2.5-cu m (88 cu ft) grapples keep the hoppers filled and can be used to feed the shear. Pieces that have been cut by the Lindemann Shear are conveyed to the regular pit by a chute. The bottom of the incinerator feed chute is equipped with a ram feed, which discharges the refuse onto a Martin grate. Undergrate (forced) air is exhausted from high in the pit area to feed the five grate zones for each furnace.

The thickened sludge from the treatment plant is mixed with polyelectrolyte and is then centrifuged to increase the solids content from 6-7 percent to 15-18 percent. The solids content is kept at this level to permit pumping the sludge. There are 4 centrifuges, one of which is a standby unit. Each centrifuge is operated for 60 hours/week at a rate of 1.2 metric tons/hr (1.3 tph) dry basis. If normal (Design) sludge quantity is processed, it is dumped on the first of twelve hearths; if the quantity is low, the sludge is fed to the third or fifth hearth. (System design calls for burning of the sludge on the ninth and tenth hearths.) Sludge-burning combustion gas temperature is kept at 800°C (1,470°F); by law, the fumes must be held at 800°C for 3 seconds. The unit is about 20 m (66 ft) high and 6 m (20 ft) in diameter. The ashes from the bottom are about 40 percent of the original solids volume and are landfilled.

All incinerator combustion fumes are moved to the scrubber by stainless steel fans through stainless steel ducts; the scrubber and stack are also made of 4,000 Series stainless steel. The scrubber treats the combustion gases from the Martin refuse incinerators as well as from the Lurgi Multiple-Hearth sludge incinerator. This Lurgi Scrubber (which uses clarifier overflow water) cools the combustion gases to 60°-70°C (140-160°F). One third of the scrubber water evaporates, and the rest is recycled by neutralizing it with lime effluent from the nearby drinking water plant, which has a lime water surplus. The settled lime sludge is disposed of with the other incinerator residue. The scrubber removes 90-95 percent of the HCl, 50-55 percent of the sulfur dioxide, and 90-95 percent of the HF. The scrubber discharge water has a pH of about 3.5 before neutralization. No odor problems have been encountered.

Miscellaneous Data

Processed in 1974:

97,000 metric tons Municipal Refuse (107,000 tons)
9,000 metric tons Industrial Refuse (9,900 tons)
106,000 metric tons Total Refuse (117,000 tons)

33,814 cu m (1.1932 x 10^6 cu ft) Sludge in 3,026 hours

Average number of furnaces in use: 2.4

Ferrous metals are separated from the residue, at a yield in 1974 of 1,998 metric tons (2,198 tons).

Capacity of Martin Furnaces with waste heat content of 1,400-2,000 kg-cal (350-500 Btu) is 7.4 metric tons per hour (8.1 tph).

Oil is not processed in this plant. This pertains to used crankcase oil as well as auxiliary fuel oil. Skimmings are a problem; they cannot be centrifuged, and will be removed manually for incineration in the future.

There are plans to use the multiple-hearth cooling air as combustion air. It is also planned in the near future to burn some industrial primary sludge from neighboring industries (duPont) in the incinerators with the Martin Grates. The duPont firm will have to dry the sludge to a consistency where the material will not stick together, so that it can be mixed with the municipal refuse. Note that the primary industrial sludge from duPont will not be burned in the Lurgi Multiple-Hearth Unit, but in the regular municipal refuse incinerators.

Figure B-5 presents a cross-section of the Dordrecht incinerator.

VISIT TO DOW INCINERATOR, DOW CHEMICAL COMPANY, MIDLAND, MICHIGAN

In November 1974, the Dow Chemical Company in Midland, Michigan was preparing a second rotary kiln incinerator for operation, with a target date May of 1975.

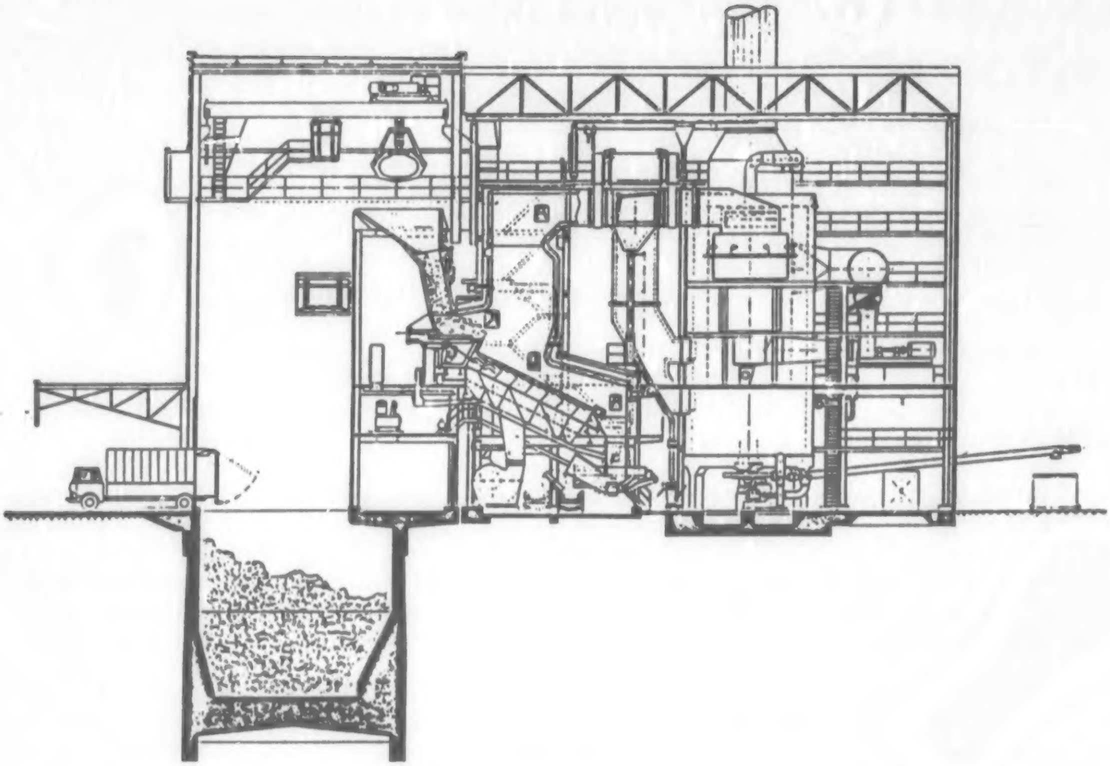


Figure B-5. Refuse Incinerator at Dordrecht, Netherlands.

The new rotary kiln installation was to be similar to Dow's present system, and would handle tars, refuse, and biological sludge. Dow is not sure what pretreatment is scheduled for the biological sludge, but will continue the present practice of firing the secondary combustion chamber.

Apparently, Dow plans to shut down the existing rotary kiln once the new one is ready. Original plans called for the installation of two kilns side by side. Present activities concern finishing the second kiln system, with whatever modifications are considered appropriate.

VISIT TO EASTMAN KODAK, REFUSE/SLUDGE INCINERATOR, KODAK PARK, ROCHESTER, NEW YORK

Eastman Kodak Company operates a combined refuse and sludge incinerator, and power boiler at its Kodak Park Complex, in Rochester, New York. The Eastman Kodak system is a Combustion Engineering VU-400 steam generating boiler equipped for suspension burning and including a dump grate. The biological sludge is dried in a Raymond Spray Dryer system, and suspension-burned in the furnace. The hot gases for the Raymond system are withdrawn from after the boiler passes and the vent gases from the Raymond system pass into the furnace proper. The boiler was designed for 3,880 kg-cal/kg (7,000 Btu/lb) refuse, and it is now running 4,880 kg-cal/kg (8,800 Btu/lb). The facility is designed to burn 164 metric tons per day (180 tpd) of refuse along with 104 metric tons per day (114 tpd) of 20 percent solids sludge. (See Flow Diagram in Figure B-6.)

Wastewater Treatment Plant

The Wastewater Treatment Plant includes both primary and secondary treatment, and produces about 13,600 kg (30,000 lbs) per day of primary and 11,400 kg (25,000 lbs) per day of secondary sludge (dry basis). The plant receives industrial wastewater at an average rate of 106,000 cu m per day (28 mgd), with very little sanitary sewage. About half of the BOD load has been identified as water-soluble solvents. Primary and secondary sludge are combined at the thickener, where they have thickened about to 4 percent solids. The sludge is then vacuum-filtered to about 20 percent solids; only synthetic polymer is used to aid filtration. Sludge solids are then hauled to the remote refuse/sludge incinerator or burned in a rotary kiln incinerator at the water treatment plant.

Sludge Drying

Sludge is stored at the incinerator until dried and burned. (This creates a significant odor problem.) A series of screw and belt conveyors moves the sludge to a mixer. Wet sludge is mixed with previously dried sludge at a ratio of about one to one; moisture content at this point is about 50 percent. The sludge is then dried in a Raymond Flash Dryer. Heat is supplied to the cage mill from the incinerator/boiler. The inlet temperature to the dryer is 540°C (1,000°F). Solids leaving the dryer contain about 15 percent moisture. (Lower moisture content would increase the potential for a dust explosion in other parts of the gas-handling system.)

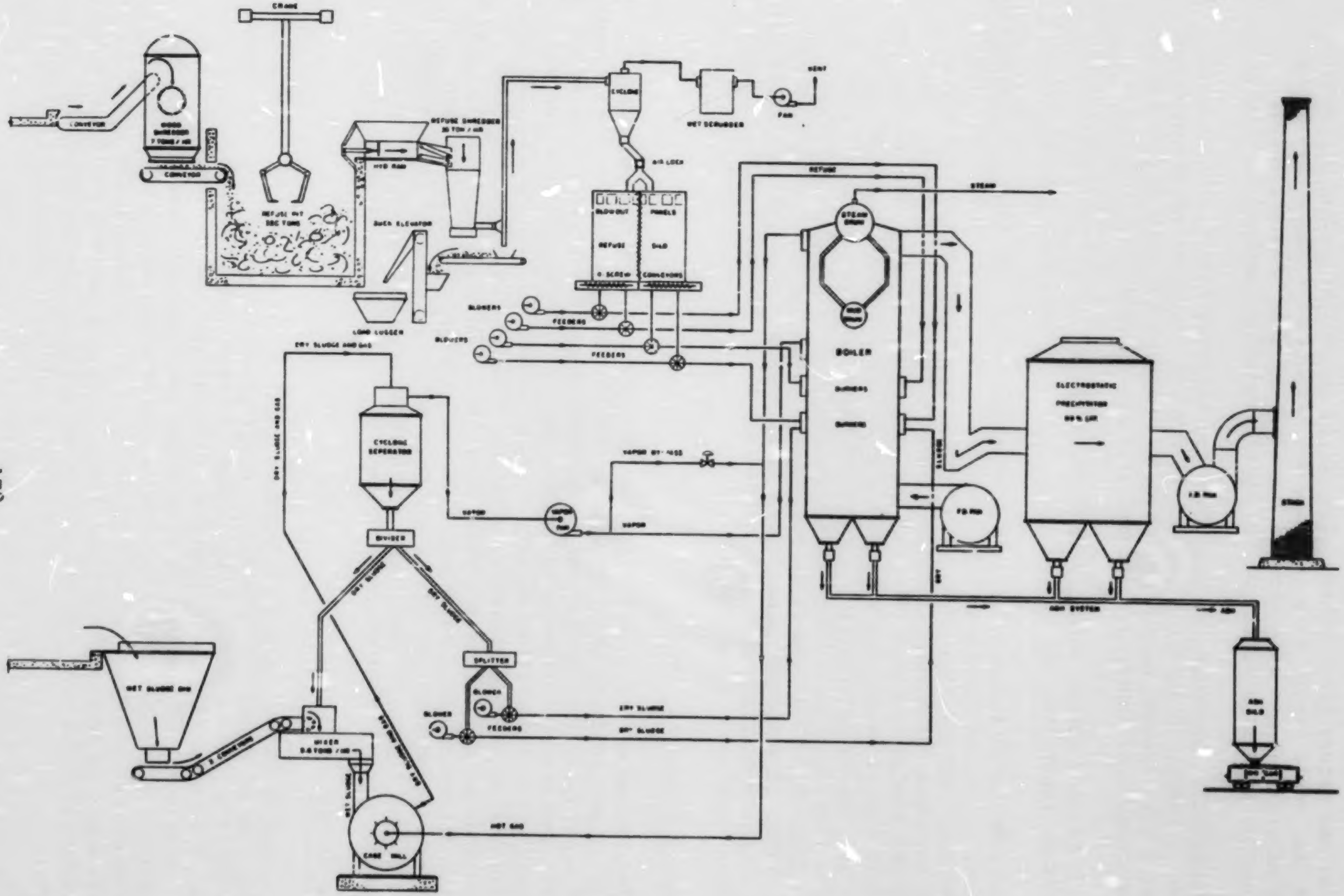

CRANE
CONVEYOR
WOOD SHREDDER
CONVEYOR
REFUSE PIT
REFUSE SHREDDER
HYD RAM
BUCK ELEVATOR
LOAD LUGGER
CYCLONE
WET SCRUBBER
FAN
VENT
AIR LOCK
BLOWOUT
PANELS
REFUSE
SCREW
CONVEYORS
BLOWERS
FEEDERS
BLOWERS
FEEDERS
REFUSE
STEAM
STEAM DRUM
MUD DRUM
BOILER
BURNERS
BURNERS
ELECTROSTATIC
PRECIPITATOR
F.D. FAN
I.D. FAN
STACK
ASH SYSTEM
ASH
ASH SILO
DRY SLUDGE AND GAS
CYCLONE SEPERATOR
VAPOR BY-PASS
VAPOR
VAPOR FAN
VAPOR
DIVIDER
DRY SLUDGE
DRY SLUDGE
SPLITTER
BLOWER
BLOWER
FEEDERS
DRY SLUDGE
DRY SLUDGE
WET SLUDGE BIN
CONVEYOR
MIXER
WET SLUDGE
CAGE MILL
HOT GAS

Figure B-6. Flow Sheet of Combustible Waste Disposal System: Eastman Kodak Company.

The dried solids are separated from the air stream in a cyclone. When only primary solids are burned, the cyclone has reasonable efficiency, but secondary solids dry to a very fine powder which is not easily separated in the cyclone. About 90 percent of the dried sludge is returned to the mixer for combination with wet sludge. The remaining 10 percent is pneumatically conveyed to the boiler. Off-gas temperature from the dryer is about 150°C (300°F). This gas, containing some small particles of sludge solids which escaped the cyclone, is returned to the combustion zone of the boiler.

Refuse Handling

Kodak's refuse consists almost entirely of waste paper and plastic. Metals, glass, etc. are salvaged. Refuse is held in a pit prior to shredding. An overhead crane charges refuse to the shredder hopper, where it is fed by means of a ram and a variable-speed converging conveyor. An Eidal 600-kW (800-hp) Shredder is used to reduce refuse size to about 5 cm x 5 cm (2" x 2"). A rotating hammer, atop the rotor, breaks any large pieces which will not fit between the rotor and shell. This breaker bar also rejects oversized metal and other objects which are not readily comminuted in the shredder. Shredded refuse is air-classified and pneumatically conveyed to a storage silo.

The silo has four out-feed screws and 12 vertical mixing screws to eliminate bridging. The feed screws charge a pneumatic conveying system, which moves the shredded refuse to the boiler.

Incinerator/Boiler

The incinerator is a tangentially fired boiler fueled with No. 6 oil, refuse, and dry sludge. (Oil is always fired, with or without the other fuels.) Oil is fired from all four corners of the combustion chamber. When firing oil only, virtually all combustion air is supplied at the burner port, and the firing rate is about 3,200 kg/hr (7,000 lbs/hr), which generates 68,200 kg (150,000 lbs) of steam per hour.

Refuse generally is burned in suspension in the combustion chamber, and any refuse not burned in suspension drops to a tipping grate. The shredded refuse is pneumatically conveyed to all four corners of the boiler. At present, only a portion of the refuse available is burned in this unit. Refuse is fired only 20 to 40 percent of the operating time. The remaining refuse is used as a fuel in an adjacent waste chemical incinerator. Kodak plans to modify the chemical incinerator to fire oil, and burn all refuse in the boiler; refuse would then be fired about 80 percent of the time in the boiler.

Dried sludge is fired from two diagonal corners of the boiler. When firing refuse, sludge, and oil, the boiler capacity is about 61,400 kg (135,000 lbs) of steam per hour, but oil consumption is reduced to 910 kg/hr (2,000 lbs/hr), or about 25 percent of the heat input. When firing refuse, very little combustion air is fired at the oil burners. Combustion air is then provided both over and under the grate.

All combustion air is preheated to 260°C (500°F) using flue gas. The boiler is a water-wall unit, providing preheated feed water. Steam pressure in preheating the boiler is about 28.2 kg/sq cm (400 psi), with 56°C (100°F) superheat. The steam is used to generate the power in a nearby turbine; or the pressure is reduced, and the steam is incorporated into the plant system.

The returning dryer off-gas, at 150°C (300°F), enters the boiler at the first tube bundle. The flue gas temperature after the boiler section is maintained at 540°C (1,000°F) to provide heat for sludge drying. The combination of low-temperature before the boiler and high flue temperature after the boiler significantly reduces its efficiency. However, by providing all combustion air under the burning refuse and by using the excess air for oil combustion, Kodak is able to limit excess air in the flue to about 25 percent.

The flue gas passes through a cooler and then to an electrostatic precipitator (rated efficiency of 99 percent). The ID fan discharges flue gas to a stack common to other combustion equipment in the area. Ash is discharged from the tipping grate in the incinerator and from the electrostatic precipitator to a pneumatic conveying system which moves the ash to a storage silo. All ash is shipped to a smelter for recovery of trace quantities of silver.

Combustion System

Disposal of general plant waste and industrial waste treatment plant sludge is accomplished by a combustion system where the waste fuels are burned in a suspension-fired boiler. Four streams of general plant waste are pneumatically conveyed into the four corners of the boiler and two streams of flash-dried sludge are pneumatically conveyed into two diagonally opposite corners of the boiler. The waste fuels are blown in tangentially to an imaginary circle in the center of the boiler. Much of the combination occurs in suspension. Any material not burned in suspension is burned on a dump grate.

The boiler is ignited by the use of No. 2 oil, and combustion is stabilized by firing No. 6 oil. The boiler is of the balanced-draft type, with a forced-draft fan and an induced-draft fan. The flue gases from the boiler are cleaned by an electrostatic precipitator and pass to a stack and then to atmosphere.

The boiler generates steam at 28.2 kg/sq cm (400 psi) and 290°C (550°F). After leaving the boiler, the steam pressure is reduced to 18.3 kg/sq cm (260 psi), and the steam is fed into an existing plant distribution system for generation of power and process work. The boiler was designed to generate 35,000 kg/hr (77,000 lbs/hr) of steam on waste fuels only, 61,400 kg/hr (135,000 lbs/hr) of steam on refuse, sludge and oil, or 68,200 kg/hr (150,000 lbs/hr) of steam on oil only.

The bottom ash from the boiler and the fly ash from the precipitator are pneumatically conveyed into an ash storage silo. The ash is unloaded from the silo into gondola railroad cars and shipped to a smelter for recovery of the silver contained in the wastes burned.

This system was first started up in early 1970 and ran at partial capacity because of material handling problems. After making system changes, eht entire facility began operating in late 1973.

VISIT TO FRANKLIN CO-INCINERATOR, FRANKLIN, OHIO

This solid waste plant, with a design capacity of 136 metric tons/day (150 tpd) of MMR and 6.4 metric ton/day (7 tpd) of MSS, has been partially funded by EPA. The sludge from the Primary Municipal Clarifier goes into the solid waste processing circuit just ahead of the press feeding the fluid-bed reactor. Also, sludge from the Secondary Clarifier is fed back into the head end of the plant, and effluent water from the sewage treatment plant is used for the Venturi Scrubber on the fluid-bed incinerator.

The process features a "Hydropulper" to shred the municipal refuse. Ferrous and non-ferrous metals, glass, and paper fiber may be removed ahead of the press feeding the fluid-bed unit. The partially dewatered material from the press is pneumatically conveyed and introduced just above the sand bed of the fluid-bed incinerator. Sufficient large material enters the fluid-bed unit such that periodically excess solids must be drained from the bed of the fluid-bed unit.

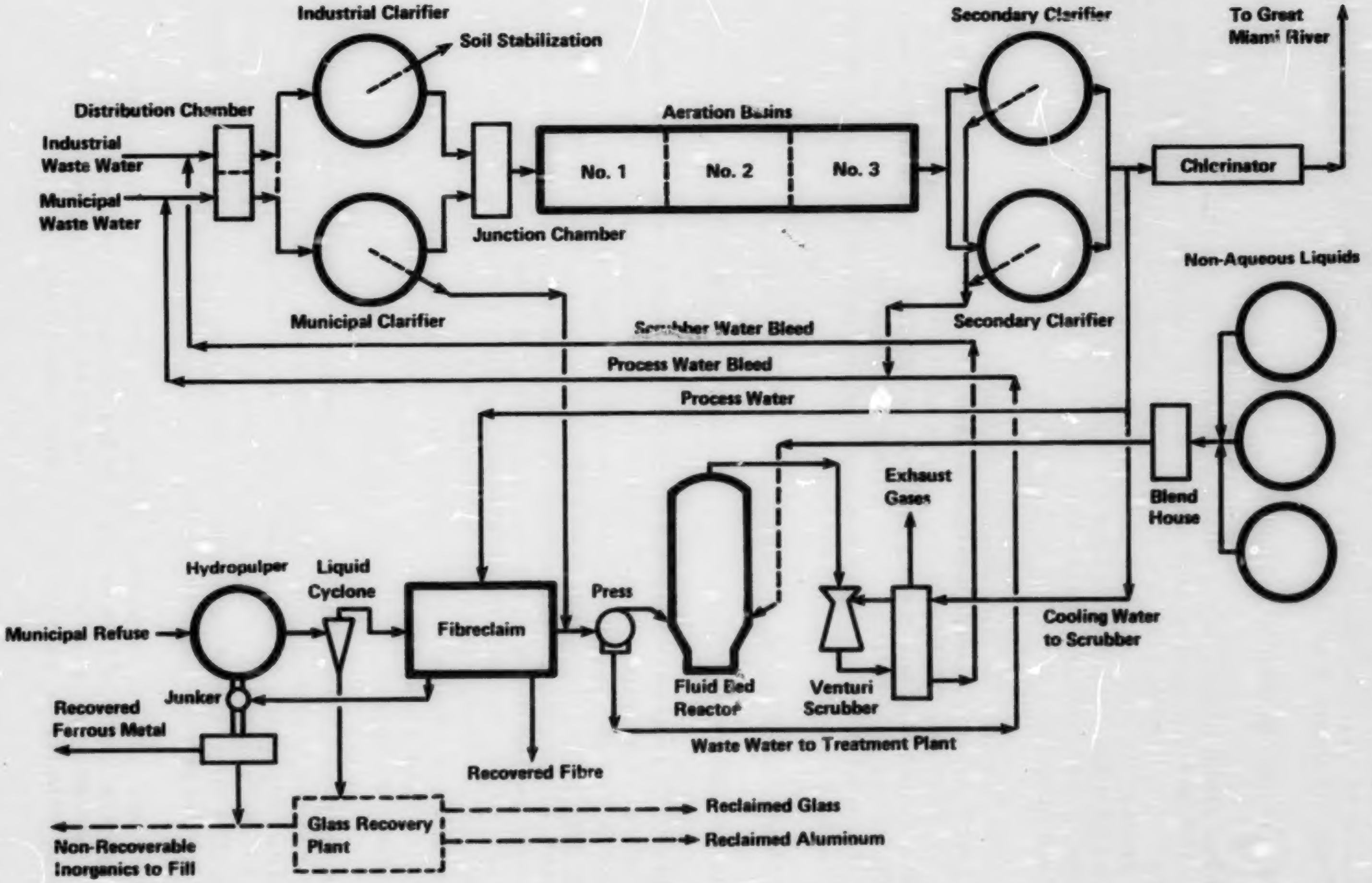
A simplified flow diagram is presented in Figure B-7.

VISIT TO HERSHEY SEWAGE TREATMENT PLANT, HERSHEY, PENNSYLVANIA

From 1963-1972 a Carver-Greenfield system was used to evaporate sewage sludge to dryness in a triple-effect unit. Oil was separated in a centrifuge and reused for a sludge suspension, and the oily sludge solids were burned in a boiler. No additional fuel was required. The sludge has a high energy content because 70 percent of the sewage is from the Hershey Chocolate Plant. During an 8-hour period about 2,270 kg (5,000 lbs) of dry sludge was burned; the make-up oil to the Carver-Greenfield system during that period was 300-380 L (80-100 gal). Sludge combustion in the boiler produced steam to evaporate/dry the raw sludge. It is not known if it was necessary to burn this much oil to make steam for evaporation, since there is no way of completely removing the oil.

There were no corrosion problems in the boiler, although some corrosion was noted on the shell side of the second effect because of the acidity of the condensate. Injection of small amounts of ammonia into the shell (controlled to pH 7.1) solved the problem. The BOD of the condensate was about 5 ppm. The most significant problem was corrosion in the dryer section and in the dry-sludge handling equipment.

The system has not been operated since 1972, and is in need of much repair. Sewage treatment will soon be handled through a regional authority (Envirotech treatment system plant), with no biological treatment. Until then, sludge at Hershey is to be digested and landfilled.



Industrial Clarifier
Soil Stabilization
Secondary Clarifier
To Great Miami River
Distribution Chamber
Aeration Basins
Industrial Waste Water
No. 1
No. 2
No. 3
Chlorinator
Municipal Waste Water
Junction Chamber
Non-Aqueous Liquids
Municipal Clarifier
Scrubber Water Bleed
Secondary Clarifier
Process Water Bleed
Process Water
Exhaust Gases
Blend House
Hydropulper
Liquid Cyclone
Press
Municipal Refuse
Fibreclaim
Cooling Water to Scrubber
Junker
Fluid Bed Reactor
Venturi Scrubber
Recovered Ferrous Metal
Waste Water to Treatment Plant
Recovered Fibre
Glass Recovery Plant
Reclaimed Glass
Reclaimed Aluminum
Non-Recoverable Inorganics to Fill

Figure B-7 Flow Sheet of Franklin (Ohio) Environmental Control Complex

VISIT TO HOLYOKE CO-INCINERATOR, DEPARTMENT OF PUBLIC WORKS, HOLYOKE, MASSACHUSETTS

The Holyoke Department of Public Works operates a sludge drying and co-incineration plant.

Raw primary sludge at 5 percent solids is vacuum filtered to a 25-30 percent consistency. The sludge cake is then dried in a 2.1 m (7 ft) diameter by 12.2 m (40 ft) long rotary kiln. Heat is supplied from the refuse incinerator and from auxiliary oil firing. Sludge leaves the drier at 85 percent solids and is incinerated with municipal and industrial refuse in one of two Pittsburgh fixed-grate incinerators. Spent gases from the dryer are returned to the incinerator for deodorization.

The plant handles about 227 metric tons/week (250 tpw) of refuse and 14.5 metric tons/week (16 tpw) of dry (85 percent) sludge, on a 5-day basis. However, sludge is dried and incinerated only three days per week. The ratio of refuse to dry sludge is therefore about 9:1 on the three days co-incineration is in operation.

Holyoke is a paper-converting town, and the incinerator plant handles both industrial and domestic refuse; until recently, the mix was 55 percent industrial and 45 percent domestic. With this ratio of high-energy industrial waste, auxiliary fuel firing in the dryer has been required only when the refuse was very wet. Some private landfill operations have opened, and the industrial/domestic ration is now 1:1. Auxiliary fuel must be fired whenever the dryer is in operation.

This plant handles about 2/3 of the sewage sludge from Holyoke, and burns about 1/2 of the refuse load. Plans call for installation of another incinerator at this site, but with no additional sludge handling capacity. The new incinerator is expected to eliminate the need for auxiliary fuel in the sludge dryer.

Incinerator

The incinerator section of the plant consists of two Pittsburgh, fixed-grate, manually stoked, natural-draft incinerators with a combined capacity of 205 metric tons/day (225 tpd)--24 hours. The plant actually operates at a rate of 51 metric tons/day--12,700 metric tons/year (56 tons/day--14,000 tons/year) on a one-shift, five-day-per-week basis. Of the 51 metric tons (56 tons), about 70 percent (9,100 metric tons/yr = 10,000 tons/yr) is typical domestic refuse; the remaining 30 percent (3,600 metric tons/yr = 4,000 tons/yr) is industrial refuse consisting primarily of wastepaper from nearby mills. The town of Holyoke generates about 10,900 metric tons (12,000 tons) of refuse per year, of which 9,100 metric tons (10,000 tons)--85 percent is incinerated. The remaining 1,800 metric tons/yr (2,000 tons/yr) are landfilled.

Until recently, the incinerator burned about 9,100 metric tons/yr (10,000 tons/yr) of industrial refuse, i.e., wastepaper; this was almost a 1:1 ratio with domestic refuse. However, particulate emissions from the pigmented paper coatings forced a significant reduction in incineration of industrial waste. Much of the industrial wastepaper is now trucked to landfill by private haulers.

Wastewater Treatment Plant

The wastewater treatment plant consists of primary treatment only. After the clarifier, sludge is thickened to 5 percent solids; the thickeners also serve as holding tanks during periods when the sludge dryer is not in operation. Thickened sludge is treated with ferric chloride/lime and then vacuum filtered. The vacuum-filtered sludge has solids content of 28 percent. Filtrate and overflow from the thickener are returned to the clarifier head box.

Overflow from the clarifier is discharged to the Connecticut River without further treatment. Secondary treatment will be implemented in the near future. The plant currently handles 65 percent of the wastewater from Holyoke--all domestic wastewater. When secondary treatment is installed, new interceptors will be included, and the plant will handle about 95 percent of all wastewater from Holyoke, including significant amounts of industrial wastewater.

Sludge Drying and Incineration

Filtered sludge cake is conveyed by belt to a pug mill, where previously dried sludge solids are added and the cake is broken. The sludge enters a 2.1-m (7-ft) diameter by 12.2-m (40-ft) long direct-fired, steel-shell rotary dryer. The dryer is equipped with lifting flights to minimize balling and to provide better gas/solid contact. The solids leave the dryer with a moisture content of about 15 percent.

The inlet temperature in the dryer is controlled to 650°C (1,200°F). The heat load of the dryer is supplied by off-gas from the incinerator and from auxiliary fuel firing. Hot gases are drawn from the incinerator at a temperature of 480-650°C (900-1,200°F); if the temperature drops below 480°C (900°F), auxiliary fuel is fired to maintain the specified inlet temperature. On the average, 30 percent of the heat load is provided by auxiliary fuel oil burning.

The spent gases leave the dryer at 150°C (300°F), pass through a cyclone and an induced draft fan, and into the incinerator stack breeching. The temperature at this point is a minimum of 480°C (900°F).

Dried sludge is conveyed to the incinerator by bucket elevator and screw conveyor. Half of the the dried sludge is diverted to the pug mill, to be mixed with the wet, vacuum-filtered sludge cake. The remainder is injected into the incinerator by a high-velocity air jet. Much of the sludge solids burn in suspension above the burning refuse.

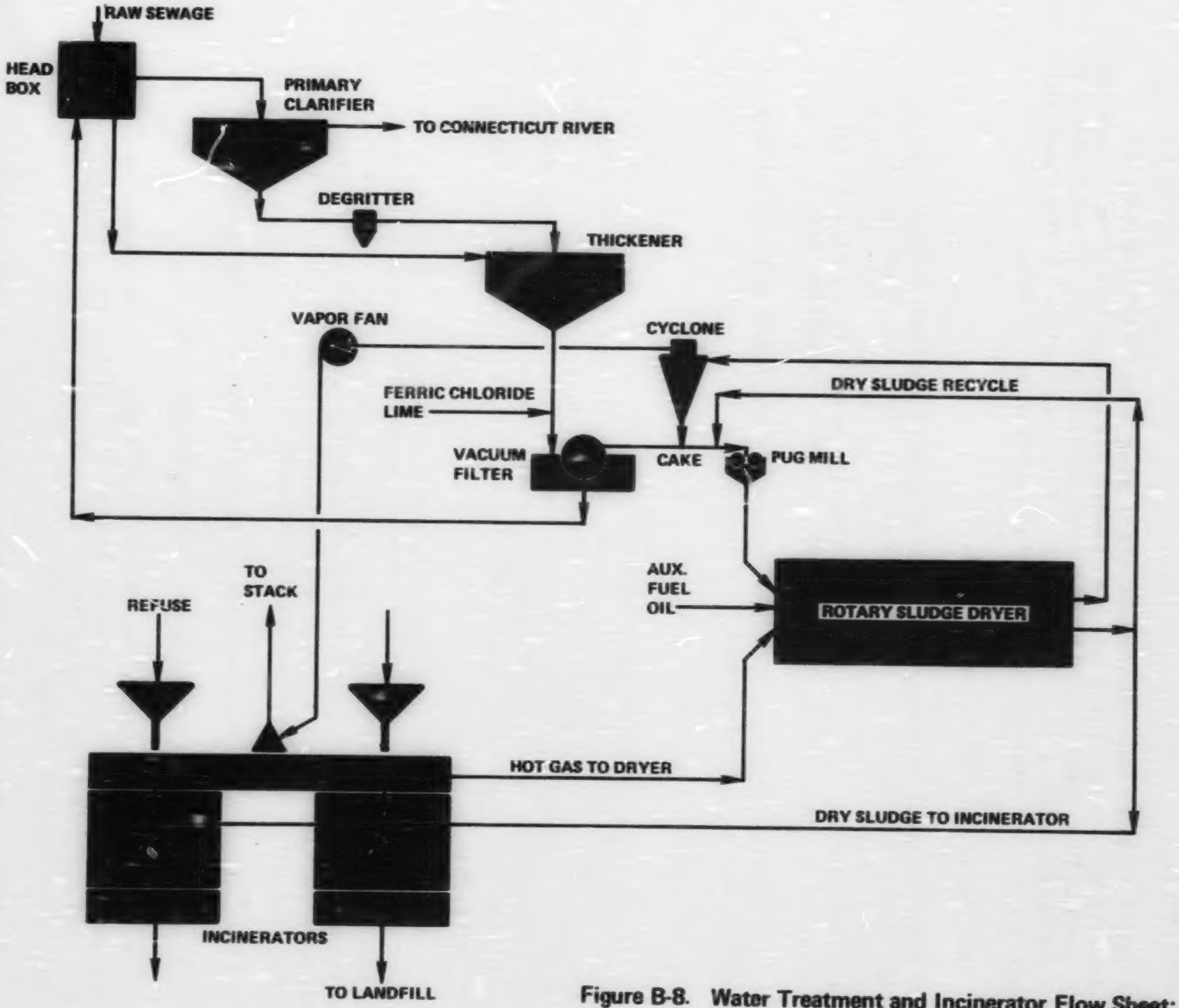

RAW SEWAGE
HEAD BOX
PRIMARY CLARIFIER
TO CONNECTICUT RIVER
DEGRITTER
THICKENER
VAPOR FAN
CYCLONE
DRY SLUDGE RECYCLE
FERRIC CHLORIDE
LIME
VACUUM FILTER
CAKE
PUG MILL
AUX. FUEL OIL
ROTARY SLUDGE DRYER
REFUSE
TO STACK
HOT GAS TO DRYER
DRY SLUDGE TO INCINERATOR
INCINERATORS
TO LANDFILL

Figure B-8. Water Treatment and Incinerator Flow Sheet: Holyoke, Massachusetts.

VISIT TO HOUSTON MUNICIPAL INCINERATOR, HOUSTON, TEXAS

Attempts to burn raw sludge in this municipal incinerator were not successful.

Local farmers pick up most of the sludge from South Houston, but occasionally, the Houston plant has excess sludge. Attempts were made to burn raw, unthickened sludge at about 95 percent moisture in an incinerator at a refuse/sludge ratio of about 3:1. This immediately extinguished the fire, and no further attempts at co-incineration were made.

Any excess sludge is landfilled.

Waste Control Systems, Inc., a division of Houston Natural Gas, which makes rotary incinerators, supplied the unit for South Houston. It was intended to burn "nearly dry" sludge, not raw sludge. The incinerator can be equipped with a screw charger for heavier materials such as sludge, and can use waste heat recovery to preheat incoming combustion air.

The company knows of no applications of co-incineration of refuse and sludge in any of its equipment.

VISIT TO LANSING FACILITIES, LANSING, MICHIGAN

Lansing previously used a Raymond Flash Dryer to produce fertilizer from sewage sludge. However, if the sludge was dried completely, it became extremely dusty, and, resultingly, little was sold. Attempts were made to reduce and dust by incomplete drying, but the remaining moisture caused the bags of packaged fertilizer-sludge to break. Fertilizer production was discontinued, and the sludge was landfilled. However, the landfill was recently condemned.

Lansing is now constructing a sludge-incineration facility, a Zimpro sludge heat treating process followed by vacuum filtration to produce a 40 percent solids sludge cake. The sludge cakes will be incinerated. No additional fuel will be used to maintain sludge combustion. Waste-heat recovery equipment will provide some heat for sludge pretreatment, but additional gas-fired boilers will be necessary.

The sludge treating facility is to be in operation by late 1975.

VISIT TO THE NEWBURGH INCINERATOR, NEWBURGH, NEW YORK

Initial attempts at co-incineration of vacuum-filtered sludge failed. They combined 25-30 percent solids sludge with trash, but the mixing was poor. As the trash was deposited on the traveling grate and burned, the sludge cake dropped through the grate.

In 1970, a Raymond flash drier was purchased. Attempts were made to get the system into operation for about one year, but were never successful. To start the operation, incinerator temperature was raised to 930°C (1,700°F) by burning cardboard. The hot gases were then directed to the flash dryer (same 25 to 30 percent solids sludge as above). The sludge would dry for 2 to 3 hours, but during this time the incinerator temperature would drop drastically; at times, temperatures went as low as 260°C (500°F). With low-temperature flue gas, sludge drying was incomplete and clogged the materials-handling equipment. The incinerator building also filled with smoke.

The incinerator is very old, with many leaks and poor draft control. The superintendent attributed this to poor operation, and believed that the system would work with a modern incinerator. Several attempts to start up again in 1974 netted the same results. Currently the sludge is landfilled, but a new incinerator is in the planning stage. There are no plans to include the dryer in the new facility.

VISIT TO REIGATE INCINERATOR, RED HILL, SURREY COUNTY, ENGLAND

The Reigate incinerator plant, a single furnace system, receives refuse in a pit and, with an overhead crane, passes the material through a Tolemach hammermill. With this mill, 910 metric tons (1,000 tons) can be processed on a set of hammers before retipping with Armalloy-37 (a product of Australia). The Tolemach mill has shown "good performance" with some pre-sorting (removal of grossly oversized material).

The shredded material from the mill is passed over a magnetic separator for the removal of ferrous metal. In moving out of the hammermill, the material is leveled to a constant head on the pan conveyor passing the magnetic separator and is thus fed at a relatively constant rate (with a drag-chain conveyor) into a Lurgi multiple-hearth furnace. Feed blockages have been a problem.

The Lurgi furnace, fired with oil at a rate of 285 L/hr (75 gal/hr) during start-up, is fed with air corresponding to 100 percent excess for refuse (averaging 6,980 J/g--3,000 Btu/lb). Thickened sewage sludge from a nearby plant is fed to the top hearth of the furnace. The combined refuse and sludge ash pass to the bottom of the furnace and into a dumpster-type container. Few problems with rabble-arm fouling have been reported.

Flue gases are passed through a duct equipped with water sprays (in case temperatures rise too high), through a Lurgi electrostatic precipitator, and up a 38-m (125-ft) high, 1.37-m (4-ft, 6-in) diameter stack. An emergency vent and a stub stack are located directly above the furnace.

The Reigate plant was commissioned in February or March of 1973 but has still not been accepted by the owners, because of a number of major and minor design and operating problems. The plant had a total cost of 686,000 pounds sterling in 1969, and it is estimated that plant costs as of 1974 would be 1.1 million pounds. By and large, this cost increase represents inflation, rather than the impact of design changes made during the start-up experience.

The Reigate plant was very clean and well-run. The sewage treatment plant in the adjacent property had a landfill available for sludge disposal, and thus was able to provide sludge on an as-needed basis. Fortunately, the plant had the options available to dispose of the sludge if problems arose in the incineration facility.

It should be noted that the tin cans separated by the magnetic separator were stockpiled in 1.2 m by 1.8 m by 1.2 m (4 ft by 6 ft by 4 ft) cages made from reinforcing bar, and that the foodstuffs and adhering paper were burned out in a separate refractory-lined, oil-fired combustion chamber. for subsequent sale as first-quality scrap.

At the time of the visit, the plant was down, to allow refractory to be applied to the metal on the central drive shaft of the multiple-hearth furnace. Problems due to local overheating (probably due to occasional high heat release during firing of refuse with a high energy content) were experienced.

Inquiries were made as to the problems concerning odor which, speculatively, could be associated with the plant (since it is similar to the Bülach plant in Switzerland). Fortunately, few people live in the region around the plant and the plant has a relatively high stack. As a consequence, odor complaints to date have been minimal. During the visit, it was noted that the sewage treatment plant next door, although not septic, had a distinctive odor.

VISIT TO SCRANTON INCINERATOR, SCRANTON, PENNSYLVANIA

Scranton uses a Raymond flash drier followed by incineration. No co-incineration is employed.

Scranton starts with a 70 percent moisture, vacuum-filtered sludge, which is then dried in the flash drier. There are facilities for bagging dried solids as fertilizer, but there is no market. Sludge is incinerated to produce heat for drying. Very little auxiliary fuel (natural gas) is used. About 19 metric tons (21 tons) of dry sludge is incinerated in 16 hours. Most of the auxiliary fuel is used to reheat the system each morning.

The only problem in the drier has been in drying sludge coagulated with polymerics. There has been no difficulty with ferric/lime treated sludge.

VISIT TO STAMFORD CO-INCINERATOR, STAMFORD, CONNECTICUT

At the time of the visit, Stamford was building a co-incineration plant, with start-up scheduled for January/February, 1975.

The sludge comes from the treatment plant at 5 percent solids (polymer-floculated). It is centrifuged to 25 percent solids and pug milled, and then enters a 2.7-m (9-ft) diameter x 18.3-m (60-ft)-long rotary kiln. The sludge is dried to 75 percent solids using the hot gases from the incinerator. The semi-dry sludge is screw fed to the top of a rocking grate incinerator.

The incinerator will burn 300 metric tons/day (330 tpd) of refuse, which typically has moisture content of 25 percent. Sludge burning capacity is designed for 9.1 metric tons/day (10 tpd) of the 75 percent solids sludge from the drier. The process design matches sludge solids and average refuse solids, for the purpose of eliminating combustion problems.

Exhaust gases from the kiln are reintroduced into the incinerator for deodorization, and an electrostatic precipitator controls particulate emissions. The incinerator has auxiliary gas burners to operate the dryer. when the incinerator is down.

Initially, the sludge will be primary, but Stamford is building a new plant for secondary treatment. They see no problem when the new treatment plant comes on line, because the ratio of sludge solids to refuse will be low.

This incinerator/sewage treatment plant handles all waste from Stamford and Darien, Connecticut.

VISIT TO TWIN CITIES, MINNEAPOLIS/ST. PAUL, MINNESOTA

A pyrolizer-incinerator for Minneapolis/St. Paul is being designed and is scheduled to be on line by 1980. Rust Engineering is the contractor for the study. Pilot work was done by Vertiteck Labs., Louisville, Kentucky, under Rust supervision.

The initial step will be heat treatment of raw sludge followed by mechanical dewatering. Vacuum filters can produce a 30 percent sludge, which can be co-incinerated at a 1:4 (dry weight) ratio with refuse. Pressure filters can produce a 45 percent solids sludge cake, which can be incinerated at a 1:2 ratio with refuse. The burning trash and sludge will supply heat for raw sludge preconditioning.

A portion of the dewatered sludge will be pyrolyzed, and the recovered fuel products will provide the heat for predrying and pyrolysis. A net output is expected from this portion of the process. Char from the pyrolysis unit will be reused in secondary wastewater treatment. All secondary sludge will be incinerated after processing as described above. Only primary sludge will be pyrolyzed.

The installation is expected to handle about 15 percent of the refuse and 15 percent of the sludge (primary and secondary) of the Minneapolis/St. Paul area. A portion of the fuel gas in incinerator afterburners may have to be used. (Note: Recent information indicates that pyrolysis plans have been abandoned.)

VISIT TO UNION CARBIDE, PUROX INCINERATOR, UNION CARBIDE CORPORATION, SOUTH CHARLESTON, WEST VIRGINIA

The prototype Purox incinerator consists of one 182-metric ton/day (200 tpd) shaft furnace using pure oxygen to burn and reduce municipal refuse to a fritted residue while producing a combustible off-gas. The furnace system has been operating at approximately 91 metric tons/day (100 tpd); Carbide personnel attribute this low capacity to the need for prudent restriction of capacity at this stage of development.

On the day of the visit, a second run using shredded refuse was performed. The first run on shredded refuse had been with a 10.2-cm (4-in.) maximum size restriction on the shredded product, and Carbide had changed the shredder for running on a 7.6-cm (3-in.) maximum size. Carbide personnel stated that it would be mid-1976 before any further attempt to incinerate raw refuse.

Prior to visiting the prototype installation, Carbide sales personnel made a lecture presentation on the Purox system. In this presentation, they utilized data that had already been published; all the data were obtained from their 4.5-metric ton/day (5-tpd) bench scale unit in Tarrytown, New York, rather than on any runs at the prototype South Charleston unit.

We believe that the shift from raw to shredded refuse was caused by problems in pyrolyzing raw refuse. Shifting from raw to shredded refuse involved adding a 150-kW (200-hp) vertical-shaft Heil shredder, along with a magnetic separator to reject the bulk of the ferrous metals. Another change was an all-new furnace charging system that cannot be used to feed raw refuse. The original configuration of the raw refuse feeder is unknown.

Mr. Jack Matthews, who is responsible for the operation of the furnace, was our tour guide. In his opinion, once the constraints on capacity are removed, Carbide will be able to easily exceed the rated capacity of the furnace.

There have been no explosions in the shredder, but the term of operation has been extremely short.

The explanation for the separation of ferrous metal from the feed material includes the following:

1. The size of the furnace hearth.
2. There is a single tap instead of dual taps, as is the practice in the foundry industry.
3. Removal of the metal was an attempt to eliminate erosion of the brick at the melt line.

Carbide personnel conducted a walk-through type of tour, starting with the floor dump arrangement for receiving refuse. A front-end loader is used to convey the raw refuse to the shredder feeder; two or three people are positioned along the feeder to hand-pick material out of the raw refuse ahead of the shredder. After shredding, a magnetic separator removes the bulk of the ferrous metal and deposits it in a tote bin. A belt conveyor conveys the shredded refuse to a feeder, which forces the material into the pressurized furnace. The hot gases leaving the furnace are quenched with a spray system positioned in the downcomer from the furnace and before any gas-cleaning equipment. It was stated that the temperature drop in this quench system was 78°C (140°F)--from 93°C to 15°C (200°F to 60°F), and that the liquid from this quench system normally went to the sewage treatment plant. The quenched gases then pass through an electrostatic precipitator of the tubular, single-field design, consisting of sixty 15.2-cm (6-in.) tubes and incorporating a 320-V system.

The furnace is lined with 90 percent alumina brick, and it was stated that the original brick was still in place, but Carbide personnel did not know the total time that the brick has been in use since start-up. The slag from the furnace is tapped out in a sealed enclosure, and drops into a water bath, from which the fritted slag is withdrawn by a drag conveyor which discharges into a tote bin.

The furnace charging system consisted of two hydraulically driven rams that alternated in feeding refuse from the chute to the furnace. The ram charging the refuse was covered by an oscillating piece while the other ram feed point was being loaded by the continuously operating conveyor. Thus, the ram being charged was always open while the other ram was feeding, and the oscillating piece would shift to load the other ram feed point. The ultimate discharge to the furnace was described as a restricted opening such that the refuse being fed provided a plug to prevent the pressurized furnace gases from exiting into the feeding compartment. However, the entire feed point was then covered with a large box which was apparently a secondary seal. We could not determine the exact configuration of this system.

VISIT TO THE UZWIL PLANT, NIEDER-UZWIL, SWITZERLAND

Municipal Sewage Treatment Plant

Sludge is generated in the treatment plant in the primary and secondary clarifiers. Primary grit, sludge, and skimmings are hauled away. Secondary sludge is digested in anaerobic digesters, which are heated by digester gas. The digested sludge is then pumped to a thickener, where it is concentrated to about 6 percent solids. The sludge production amounts to 20-25 cu m (710-880 cu ft) per 24-hour operating day, at 6 percent solids content when introduced into the incinerator. Secondary clarifier effluent is used in the incinerator scrubber.

Incinerator Installation

The plant operates 5 days per week, 24 hours per day. Refuse is received and stored in the refuse pit, with oversize items diverted to a separate location. The refuse is loaded on a conveyor that transports it to a hammermill. Reduction size appeared to be about 7.6 to 10.2 cm (3 to 4 in.).

The material then passes a magnetic drum, where all ferrous metal is removed. The separated ferrous metal appeared clean, with very little entrainment of other materials.

The remaining material is then conveyed onto a vibrating screen with 30-mm (1.2 in.) holes. The oversized material is transported to the top of the multiple-hearth furnace by a vertical drag-link conveyor; the sludge is also introduced at this location.

The undersized material is fed into another shredder, where it is reduced to 1.3 to 0.64 cm (1/2 in. to 1/4 in.) size. This material is then mixed with some sludge from the clarifier and stored for composting (or loaded on trucks).

The multiple-hearth (Nichols) incinerator has three burners for auxiliary heating. These nozzles introduce used oil (crankcase oil, etc.) with three pumps, each with a capacity of 12 liters per hour (3.2 gph) to introduce supplemental fuel when required to maintain proper hearth temperature. Not all burners are used at the same time; one, two, or three can be used, as required.

The first and second (from the top) stages have been removed from the twelve-hearth incinerator.

The temperatures observed during the visit were:

Hearth 1 (top of furnace)	880°C (1,620°F)
Hearth 4 (now Hearth 2)	840°C (1,540°F)
Hearth 7 (now Hearth 5)	880°C (1,620°F)

The combustion gases pass first through a primary scrubber (in essence a large vertical duct), where clarifier effluent is introduced into the downward gas stream. This duct then connects into a 180° vertical bend, where the spray water that has not evaporated is drained off the heel. The combustion gases are ducted to a secondary scrubber, consisting of two layers of Rasching Rings and spray nozzles. The sprays are fed with secondary clarifier effluent water. An induced-draft fan conducts the scrubbed gases to the chimney. There have been very few problems with incinerator odors.

Municipal refuse is burned at a rate of roughly 78-80 metric tons per day (86-88 tons per day)--24 hours a day, and about 20-25 cu m (710-880 cu ft) of digested sludge at 6 percent solids is incinerated daily.

A special furnace (2.5 metric tons charge volume--88 cu ft) incinerates oversize items, such as mattresses, tires, etc., that have been stored. The combustion gases from this furnace are then fed to the Nichols Furnace, which acts as a secondary combustion chamber to provide complete combustion of any possible odors, smoke, etc.

REVIEW OF WASTE DISPOSAL OPERATIONS, WATERBURY, CONNECTICUT

Operational December 1951 and rehabilitated in 1968:
Two 136 metric ton/day (150-tpd) Batch-Fed Nichols monohearths to burn the raw refuse, and a Combustion Engineering Raymond Flash drying System to dry the dewatered primary sludge. The primary sludge is dewatered from 94 percent to 70 percent moisture on vacuum filters using ferric chloride and lime for conditioning. The flash-dried sludge is screw-conveyed to one of the two furnaces, but no details on feed method are included in available data.

Dewatered sludge is available from the incinerator; the incinerator also provides hot water for the plant. The hot water heater may be fired with fossil fuel.

From the 1963 Annual report, we note that:

> "Several major repairs at the incinerator cut heavily into the normal burning time. This, together with abnormally high moisture content of the refuse due to the very high rainfall, reduced the average burning rate and forced us to bypass about 10.5 percent of all incoming material directly to landfill."

The report further states that on curved per capita basis the MMR "breaks down to 1,530 pounds (695.5 kg) per year or 4.2 pounds (1.9 kg) per person per day."

In 1973, the sludge to the filters averaged 4.58 percent dry solids and was dewatered to 28.2 percent solids. After flash drying, the percent dry solids was 49.9 percent.

All the sludge in 1973 was burned in Furnace No. 1 and it appears that this is the only furnace equipped for sludge burning. Waterbury burned 25,035,000 kg (55,077,000 lbs) of refuse along with 2,811,000 kg (6,184,000 lbs) of sludge. (We are assuming that the sludge is reported as fired.) Following rehabilitation of the furnaces, which included the addition of wetted baffle collectors and new high stack, the stack was tested for particulate emissions in 1968. The following results were obtained:

Refuse Burning	0.528 kg/1,000 kg of flue gas
Sludge and Refuse	0.497 kg/1,000 kg of flue gas

LIST OF CO-INCINERATION INSTALLATIONS

From catalogues and installation lists, the following list of sludge flash drying co-incineration installations was compiled:

Location	Status
Watervliet, New York (1940)	Shut down
Waterbury, Connecticut (1951)	Standby
Bloomsburg, Pennsylvania (1953)	Abandoned
Louisville, Kentucky (1959)	Not co-incinerating
Neenah-Menasha, Wisconsin (1958)	Shut down
New Albany, Indiana (1959)	Shut down
Trenton, Michigan (1964)	Drying only
Newburgh, New York (1971)	Abandoned

There is another installation at Eastman Kodak in Rochester, New York (visited) and two rotary dryer installations at:

Holyoke, Massachusetts (1965)	Visited
Stamford, Connecticut (1975)	Recent start-up

The notations on status are based upon contact with Mr. George Simons, Mr. R.D. Nickerson, and Mr. J.H. Fernandes of Combustion Engineering, supplemented by contact with owner-operator and by plant visits. When the status is "contacted" or "visited", a separate report is included in the Appendix.

APPENDIX C

GENERATION AND HANDLING OF WASTEWATER TREATMENT SLUDGES

SOURCES AND EXTENT OF SLUDGE GENERATION

Suspended solids are usually present in the influent to municipal wastewater treatment plants, at concentrations of 100 to 300 mg/l. In addition, suspended solids are generated in biological and chemical precipitation processes. These solids form the major by-product of a municipal wastewater treatment plant: sludge.

The solids, removed by a variety of methods in wastewater treatment plants, include grit, screenings, and scum, as well as sludge. (Grit, screenings, and scum are not normally considered sludge.) Sludge is by far the largest in volume, and its processing and disposal constitute perhaps the most complex problem with which the engineer is faced in the field of wastewater treatment.

"Sludge" is a broad term used to describe the various aqueous suspensions of solids encountered during wastewater treatment. The nature and concentration of the solids control the processing characteristics of the sludge. The unit processes used for capture, concentration, dewatering and disposal of the solids encountered in municipal wastewater treatment plant operations are frequently the most sensitive to changes and most difficult to design.

The full impact of the problems associated with disposal of the mixed sludges resulting from secondary treatment has only recently begun to be realized fully in the U.S. Coincidentally, the technical literature on sludge reflects the growing concern for these problems. (All the entries in the References Section for this document are from 1970 or later.) EPA has published a technology transfer document[1] on sludge treatment and disposal, following up on previous EPA studies by Burd[2] and Balakrishnan.[3] The Burd report is a comprehensive review of sludge handling and disposal practices, while the Balakrishnan report deals specifically with sludge incineration methodology. EPA has funded a number of other specific studies, and recently many articles on sludge generation, production, handling, and disposal have appeared in the literature.

The quantity of sludge produced in treating domestic sewage is a function of wastewater characteristics and of the degree of treatment required to meet effluent guidelines. The Federal Water Pollution Control Act Amendments of

1972[4] require application of secondary treatment as a minimum, with provision for applying (by 1983) the best practicable control technology.

WASTEWATER CHARACTERISTICS

The composition and concentration of wastewater constituents will vary with time, sources, water quality, and the condition of the sewer system. For any given area, the quantity and quality of the sewage should be determined and used in the design of the sewage treatment works. For the purposes of feasibility studies, typical sewage characteristics and flows, as presented in Table C-1, are defined and can be used to calculate pollutant loadings in municipal sewage. For example, with the medium concentrations of Table C-1 and the widely used water usage rate of 380 liter/capita/day (100 gal/capita/day), the suspended solids loading is 0.077 kg/capita/day (0.17 lb/capita/day), and the BOD_5 loading is also 0.077 kg/capita/day (0.17 lb/capita/day).

Zanoni and Rutkowski[6] have published a summary of literature findings on per capita loading values. They reported that suspended solid values range from 0.060 to 0.150 kg/capita/day (0.132-0.324 lb/capita/day), and BOD values from 0.045 to 0.12 kg/capita/day (0.099 to 0.26 lbs/capita/day), with five of eight sets of BOD data known to be on a total demand basis. The authors also report studying an area that is entirely residential and report the following data, representing strictly domestic wastewater, which includes 30 percent usage (reportedly the nationwide average) of garbage grinders:

Characteristics	Value (per capita per day)		
	kg		lb
BOD (5-day, 20°C)	0.045		0.10
COD	0.090		0.20
BOD: COD ratio		1:2	
SS	0.036		0.08
Wastewater flow			
l/day/cap		220	
gpd/cap		58	

These loading values correspond to concentrations of 165 mg/l of suspended solids and 207 mg/l of BOD_5, which approximate the medium concentrations reported in Table C-1. Since it is impractical to isolate domestic sewage totally from commercial, institutional, and light industrial sources or to prevent sewer infiltration totally, the use of sewage at medium strength and of a flow rate of 380 l/capita/day (100 gpcd) is a reasonable basis for determining sewage sludge generation rates.

WASTEWATER TREATMENT PROCESSES AND SLUDGES INVOLVED

The combinations of wastewater treatment unit processes are virtually infinite, but can be categorized under the general headings of primary, secondary and tertiary treatment. Figure C-1, from Eckenfelder and Ford[7],

TABLE C-1. TYPICAL COMPOSITION OF DOMESTIC SEWAGE[5]
(All values except settleable solids are expressed in mg/liter)

Constituent	Concentration		
	Strong	Medium	Weak
Solids, total	1,200	700	350
Dissolved, total	850	500	250
Fixed	525	300	145
Volatile	325	200	105
Suspended, total	350	200	100
Fixed	75	50	30
Volatile	275	150	70
Settleable solids, (ml/liter)	20	10	5
Biochemical oxygen demand, 5-day, 20°C (BOD_5-20°)	300	200	100
Total organic carbon (TOC)	300	200	100
Chemical oxygen demand (COD)	1,000	500	250
Nitrogen, (total as N)	85	40	20
Organic	35	15	8
Free ammonia	50	25	12
Nitrites	0	0	0
Nitrates	0	0	0
Phosphorus (total as P)	20	10	6
Organic	5	3	2
Inorganic	15	7	4
Chlorides*	100	50	30
Alkalinity (as $CaCO_3$)	200	100	50
Grease	150	100	50

*Values should be increased by amount in carriage water.

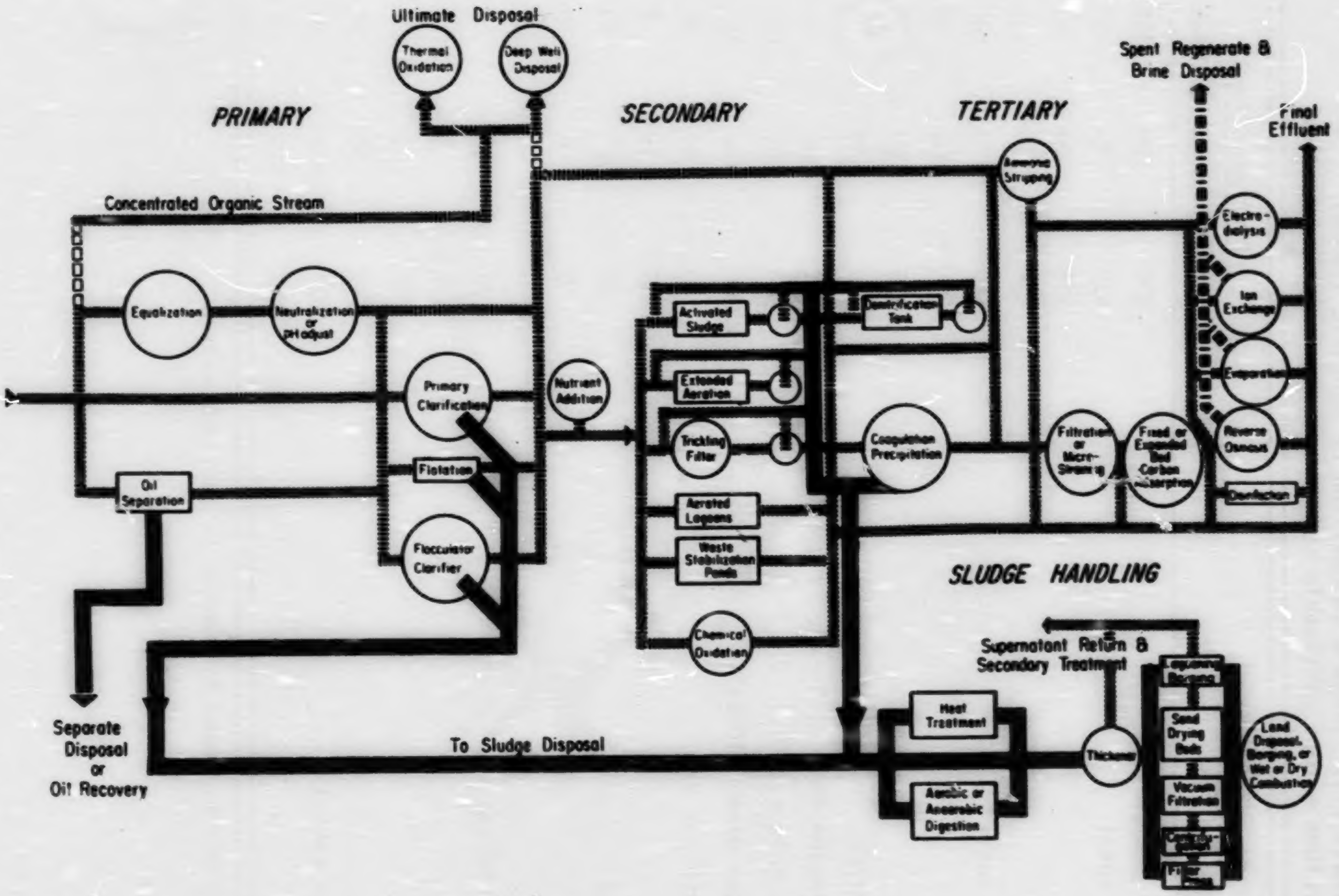

Ultimate Disposal
Thermal Oxidation
Deep Well Disposal
PRIMARY
SECONDARY
TERTIARY
Spent Regenerate & Brine Disposal
Final Effluent
Concentrated Organic Stream
Equalization
Neutralization or pH adjust
Primary Clarification
Flotation
Flocculator Clarifier
Oil Separation
Separate Disposal or Oil Recovery
Nutrient Addition
Activated Sludge
Extended Aeration
Trickling Filter
Aerated Lagoons
Waste Stabilization Ponds
Chemical Oxidation
Denitrification Tank
Coagulation Precipitation
Ammonia Stripping
Filtration or Micro-Straining
Fixed or Expanded Bed Carbon Adsorption
Electro-dialysis
Ion Exchange
Evaporation
Reverse Osmosis
Disinfection
SLUDGE HANDLING
To Sludge Disposal
Heat Treatment
Aerobic or Anaerobic Digestion
Thickener
Supernatant Return & Secondary Treatment
Lagooning Barging
Sand Drying Beds
Vacuum Filtration
Centrifugation
Filter Press
Land Disposal, Barging, or Wet or Dry Combustion

Figure C-1. Wastewater Treatment Processes: Substitution and Sequence Diagram.

indicates the multiplicity of available options, from which the designer and operator select the one most appropriate, based on wastewater characteristics, effluent quality requirements, and system cost. The sludges produced in treating wastewaters must be disposed of, and Figure C-2 shows alternative sludge processing steps that are feasible and widely used.

Conventional primary sedimentation plus aerobic secondary treatment produces sludges which contain only a minimal amount of inert material and are largely combustible, although the sludge solids are still tied up with copious quantities of water. After incineration, only the inert ash remains to be disposed of. Sludge incineration may, therefore, be considered a sludge-processing step that burns the organics, evaporates the remaining water, and reduces sludge solids to a much smaller volume and weight (of organics) for ultimate disposal.

The addition of inorganic chemicals to the primary or secondary clarifiers of a conventional wastewater treatment plant to improve removal of solids and BOD and/or phosphorus is a suspect procedure when the sludges produced are to be incinerated before ultimate disposal of the residue. The addition of inorganic chemicals (lime and the salts of iron or aluminum) increases both the mass and the volume of sludge to be handled. The non-combustible inorganics reduce the heating value of the dry sludge solids and increase the quantity of incinerator residue. When the sludge solids are incinerated with refuse, the sludge and refuse residues are mixed, and any opportunity to recover chemical values is lost.

Addition of synthetic organic polyelectrolytes, either in the primary or secondary treatment process, is an alternative to addition of inorganic chemicals that can be used advantageously to improve the overall performance of the treatment system. The combustible organics added are easily incinerated and do not deliberately increase the quantity of incinerator residue.

In tertiary treatment, the use of inorganic chemicals to treat the effluent from a primary-secondary treatment system allows segregation of the resulting, largely inorganic, sludges produced. These sludges can then be handled, processed, recycled, and disposed of independently of the largely combustible solids produced in conventional secondary treatment. The wastewater treatment model can, therefore, be defined as primary sedimentation and aerobic secondary treatment producing a reasonably combustible sludge.

Sludge Quantities

The quantity of raw dry sludge solids produced by the model wastewater treatment plant designed for an effluent suspended solids of 20 mg/l and BOD of 14 mg/l is approximately 0.091 kg/capita day (0.20 lb/capita/day). The inert portion of the dry solids is approximately 20 percent. This sludge quantity was calculated on the basis of medium-strength sewage (Table C-1), 380 l/capita/day (100 gpcd), and Vesilind's[8] adaptation of the method proposed by Kormanik[9].

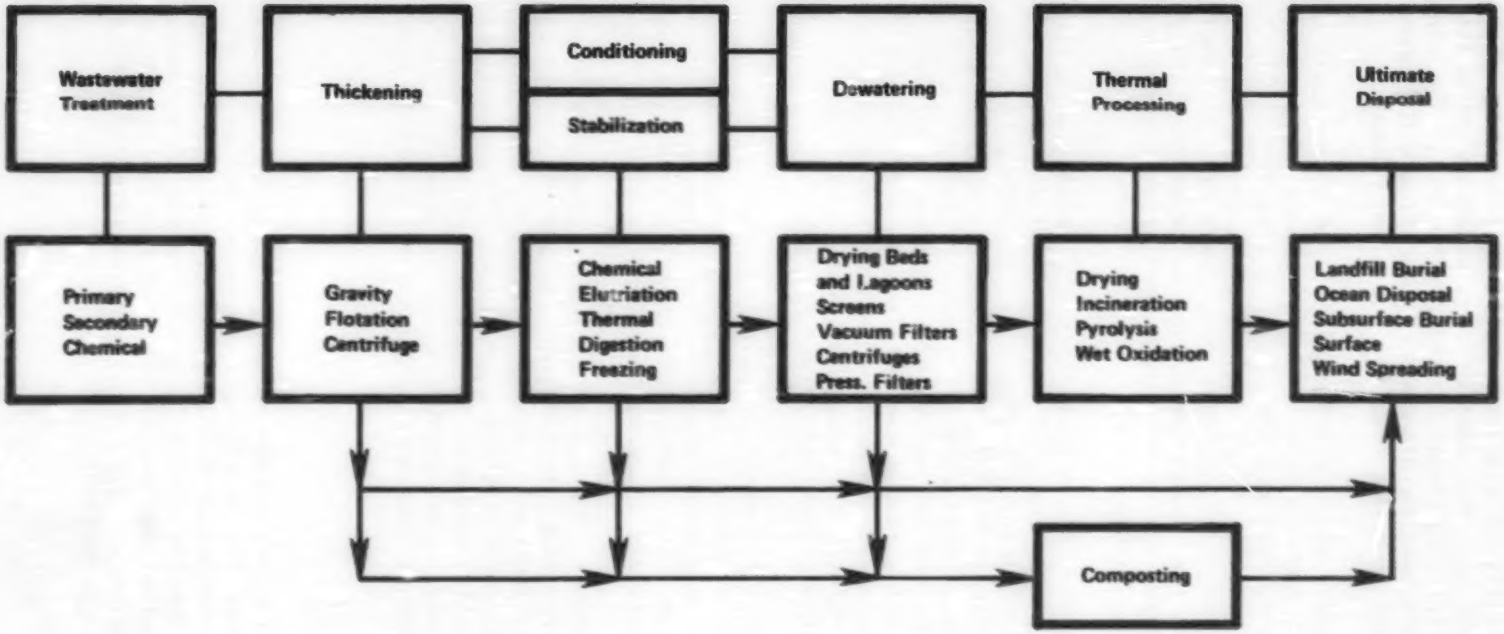

Wastewater Treatment
Thickening
Conditioning
Stabilization
Dewatering
Thermal Processing
Ultimate Disposal
Primary
Secondary
Chemical
Gravity
Flotation
Centrifuge
Chemical
Elutriation
Thermal
Digestion
Freezing
Drying Beds and Lagoons
Screens
Vacuum Filters
Centrifuges
Press. Filters
Drying
Incineration
Pyrolysis
Wet Oxidation
Landfill Burial
Ocean Disposal
Subsurface Burial
Surface
Wind Spreading
Composting

Figure C-2. Alternative Sludge Handling Process and Systems.

Sludge Composition and Heating Value

The ultimate analysis of dry and ash-free sludge solids has been estimated[10] as follows:

Element	Molecular Weight	Percent
Carbon, C	12	55
Hydrogen, H_2	2	6
Oxygen, O_2	32	35
Nitrogen, N_2	28	3
Sulfur, S	32	1

The average high heat value for these dry volatile solids has been estimated[10] at 5,550 kg-cal/kg (10,000 Btu/lb).

SLUDGE HANDLING AND PROCESSING

Sludge Stabilization

As shown in Figure C-1, the sludge to be wasted can be processed by heat treatment or by digestion (aerobic or anaerobic). The net result of either of these stabilization/reduction steps is to reduce the combustible organic content of the resultant sludge. Anaerobic digestion of the raw sludge produced by the model system reduces the heating value of the sludge by 25 percent. Heat treatment reportedly[8] produces such a strong supernatant that, when recycled to the treatment plant, it might increase plant design capacity by as much as 15 percent.

Therefore, sludge stabilization/reduction process steps warrant no further discussion or consideration in exploring the feasibility of the co-incineration of sewage sludge and municipal refuse. We can now simplify the sludge-handling options. The principal processing steps that are potentially useful as preliminary to thermal destruction or incineration are included in Figure C-2.

Sludge Thickening

The contaminants removed from the wastewater in the form of a dilute aqueous sludge are typically concentrated by thickening, and the excess water is returned to the head end of the treatment system. Gravity and flotation thickeners are normally used, but, where space limitations or sludge characteristics dictate, centrifuges may be more appropriate. Thickening is used at most wastewater treatment plants, because it is an efficient means of reducing the volume of sludge to be handled in subsequent processing steps.

Gravity Thickeners--

Both solids loading and hydraulic loading must be considered when designing gravity thickeners. The following solids loadings have been used for thickener design for different types of sludge:

Type of Sludge	Underflow Concentration	Average Solids Loading (per day)	
	percent, TS	kg/sq m	lbs/sq ft
Primary	8-10	100	20
Primary and Trickling Filter	6-8	60	12
Primary and Waste Activated (60:40 Weight Ratio)	3-6	40	8

Most thickeners are operated at a hydraulic loading of 2,400-3,300 liter/sq m (600-800 gpd/sq ft). Thickeners with hydraulic loadings less than 1,600 liter/sq m (400 gpd/sq ft) have been found to produce odors.

Primary sludges are readily thickened in gravity thickeners, but waste activated sludges are difficult to thicken; in both cases, the reduction in sludge volume achieved by concentration is considerable. Experience with biological sludge indicates that the sludge maintains its integrity in terms of consolidation characteristics when mixed with other sludges. That is, for a known quantity of primary and activated sludge, the floor loading and underflow concentration can be calculated on a proportionate basis. It is seldom desirable to achieve a solids concentration in excess of 10 percent, because the thickened sludge would be viscous and very difficult to pump.

In summary, gravity thickening of combined primary and activated sludges can produce a sludge containing 4 to 8 percent solids.

Flotation Thickeners--

Air flotation thickeners are better than gravity thickeners for waste activated sludge. They can thicken this type of sludge to 6 percent, whereas the maximum attainable by gravity thickeners is 2-3 percent. The air flotation process can also be applied to mixtures of primary and waste activated sludge. The greater the ratio of primary sludge to waste activated sludge, the higher the permissible solids loading to the flotation unit. Because of its high operating cost, air flotation generally is considered only for thickening waste activated sludge. Table C-2 summarizes typical parameters used in the design of air flotation thickening units.

TABLE C-2. TYPICAL AIR FLOTATION DESIGN PARAMETERS

Parameter	Values
Air Pressure,	
kg/sq cm	3-5
psig	40-70
Effluent Recycle Ratio, percent of Influent Flow	30-150
Air-to-Solids Ratio, weight air/weight solids	0.02
Solids Loading, average	
kg/sq m/day	50 (100-200)*
lb/sq ft/day	10 (20-40)*
Polyelectrolyte Addition,	
kg/metric ton dry solids	0 (2-4)
lb/ton dry solids	0 (5-10)
Solids Capture, percent	70-90 (90-96)
Total Solids, percent:	
Unthickened	0.5-1.5
Thickened	4-6

*Figures in parentheses denote values with polyelectrolyte addition.

Typical operating data for various air flotation units are presented in Table C-3. Combined primary and activated sludge produces a more concentrated float sludge than does waste activated sludge alone. Polymer and/or chemical addition permits greater solids loading and improves solids recovery without substantially increasing the float solids concentration.

Sludge Dewatering

A sludge dewatering process is one which removes sufficient water from sludge so that its physical form is changed from essentially that of a fluid to that of a wet solid cake. The principal sludge dewatering methods are vacuum filtration, centrifugation, and pressure filtration.

Vacuum Filtration--

Vacuum filtration is the most commonly used mechanical sludge dewatering method in the United States. Conditioning of wet sludge is necessary to achieve satisfactory yields from vacuum filters. Conditioning coagulates the sludge particles and allows the water to drain freely. As a result, a

TABLE C-3. AIR FLOTATION THICKENING PERFORMANCE

Type of Sludge	Solids Loading kg/sq m/day	Solids Loading lbs/sq ft/day	Feed Solids percent	Float Solids percent	Solids Recovery percent
Waste Activated	60-90	12-18	0.5 to 1.5	4.0 to 6.0	85 to 95
Waste Activated*	120-230	24-48	0.5 to 1.5	4.0 to 5.0	95 to 99
Waste Activated	68	13.9	0.81	4.9	85
Waste Activated	35	7.1	0.77	3.7	99
Waste Activated	97	19.8	0.45	4.6	83
Waste Activated	128	26.2	0.80	6.5	93
Waste Activated	141	28.8	0.46	4.0	88
Combined Primary and Waste Activated	120-230	24-30	1.5 to 3.0	6.0 to 8.0	85 to 95
Combined Primary and Waste Activated	100	21	0.64	8.6	91
Combined Primary and Waste Activated	227	46.6	2.30	7.1	94

*1.2 to 2.4 kg polyelectrolyte/metric ton (3-6 lb/ton) dry solids.

thicker filter cake is produced and the drum can be rotated at a higher speed. The filtrate contains a high concentration of fine suspended solids and is returned to the treatment plant.

The number and size of filters are based on the type of sludge to be filtered and the number of hours of operation. At small plants, 30 hr/wk constitutes a normal schedule; at large plants, 20 hr/day may be necessary. The remaining hours in the day are used for conditioning, clean-up, and possible delays. A plant may be designed for one-shift operation initially, and for two- to three-shift operation of the same filters when the plant is expanded to provide for increased sewage flows.

The performance of a vacuum filter is measured in terms of the yield of solids on a dry weight basis, expressed as pounds per square foot per hour (kg/sq m/hour). The quality of the filter cake is measured by its moisture content expressed as a percent of the total (wet) weight.

Filters are operated to obtain the maximum production consistent with the desired cake quality. Where the cake is to be heat-dried or incinerated, the moisture content is a critical item, since all the water remaining in the cake must be evaporated to steam. Typical performance data are shown in Tables C-4 and C-5. Typical vacuum filtration chemical conditioning dosage rates are shown on Table C-6.

TABLE C-6. ESTIMATED CHEMICAL CONDITIONING DOSAGE*
FOR VACUUM FILTRATION+

Type of Sludge	CaO Dose	$FeCl_3$ Dose	Polymer Dose
	lbs/ton	lbs/ton	lbs/ton
Primary Sludge	176	42	5
Limed Primary (212 lb CaO/ton)	0	42	5
Digested Primary Sludge	240	76	20
Digested/Elutriated Primary	0	68	9
Raw (Primary + EAS)	200	52	18
Limed (Primary + EAS)	0	40	5
Digested (Primary + EAS)	372	110	36
Digested/Elutriated (Primary + EAS)	0	125	24

*Source: EPA Process Design Manual for Sludge Treatment and Disposal.
+1 lb/ton = 0.412 kg/metric ton.

A vacuum filter can dewater combined (primary and secondary) thickened sludge to approximately 20 percent solids (range 16-25 percent). Inorganic chemicals and/or polyelectrolytes are used to condition the sludge before filtration. Typical inorganic chemical dosage rates are 2-6 percent ferric chloride ($FeCl_3$) and 10 percent lime (CaO) used together.[1] Alternatively, 0.9 percent of a polymer can be used. All dosage percentages are expressed as percent additions to dry sludge solids.

TABLE C-4. TYPICAL ROTARY VACUUM FILTER RESULTS FOR SLUDGE CONDITIONED WITH INORGANIC CHEMICALS*

Type Sludge	Chemical Dose, kg/metric ton (lb/ton) Ferric Chloride	Lime	Yield, kg/sq m/hr (lb/sq ft/hr)	Cake Solids percent
Raw Primary	0.4-0.8 (1-2)	2.5-3.3(6-8)	30-40 (6-8)	25-38
Anaerobically Digested Primary	0.4-1.2 (1-3)	2.5-4.1 (6-10)	25-40 (5-8)	25-32
Primary + Humus	0.4-0.8 (1-2)	2.5-3.3 (6-8)	20-30 (4-6)	20-30
Primary + Air Activated	0.8-1.6 (2-4)	2.9-4.1 (7-10)	20-25 (4-5)	16-25
Primary + Oxygen Activated	0.8-1.2 (2-3)	2.5-3.3 (6-8)	25-30 (5-6)	20-28
Digested Primary and Air Activated	1.6-3.6 (4-6)	2.5-7.8 (6-19)	20-25 (4-5)	14-22

*Source: EPA Process Design Manual for Sludge Treatment and Disposal.

TABLE C-5 TYPICAL ROTARY VACUUM FILTER RESULTS FOR POLYELECTROLYTE-CONDITIONED SLUDGES*

Type Sludge	Chemical Cost, $/metric/ton	($/ton)	Yield, kg/sq m/hr	(lb/sq ft/hr)	Cake Solids percent
Raw Primary	1-2	(1-2)	40-50	(8-10)	25-38
Anaerobically Digested Primary	2-6	(2-5)	35-40	(7-8)	25-32
Primary + trickling filter Humus	3-7	(3-6)	20-30	(4-6)	20-30
Primary + Air Activated	6-13	(5-12)	20-25	(4-5)	16-25
Primary + Oxygen Activated	6-11	(5-10)	20-25	(4-6)	20-28
Anaerobically Digested Primary and Air Activated	7-16	(6-15)	17-30	(3.5-6)	14-22

*Source: EPA Process Design Manual for Sludge Treatment and Disposal.

Centrifugation--

Centrifuges of various types have been employed for solid-liquid separation processes in agriculture and industry for at least 50 years. For almost 25 years, the continuous solid-bowl conveyor-type centrifuge has been used for dewatering municipal sludges. Objectives of centrifugal sludge dewatering are the same as for rotary vacuum filtration. Sludge is fed into the rotating bowl at a constant flow rate, and separates into a dense cake containing the solids and a dilute stream called centrate. The centrate contains fine, low-density solids, and is returned to the raw-sludge thickener or primary clarifier.

Centrifuges can produce dewatered cakes generally comparable to those obtained by vacuum filtration. Polymers are used to improve the solids recovery, but produce a slightly wetter cake. A summary of results achievable with various sludges is shown in Table C-7.

TABLE C-7. TYPICAL SOLID-BOWL CENTRIFUGE PERFORMANCE*

Wastewater Sludge Type	Solids	Solids Recovery	Chemical Addition
	percent	percent	
Raw or digested primary	28-35	70-90 (50-70)+	no
Raw or digested primary, plus trickling filter humus	20-30	80-95	yes
		60-75	no
Raw or digested primary, plus activated sludge	15-30	80-95	yes
		50-65	no

*Source: EPA Process Design Manual for Sludge Treatment and Disposal.
+New data indicate performance is in this range.

Pressure Filtration--

Properly conditioned sludge can be dewatered in filter presses to very high solids levels. Experience in the United States with pressure filtration of municipal sludges has been limited. Table C-8 indicates typical sludge concentrations that can be produced using pressure filtration, with the addition of ash or a combination of ferric chloride and lime. These data are based on European experience.

Filter presses can produce drier cakes than can vacuum filters or centrifuges. Sludge conditioning is required, and pre-coating with inert ash, diatomaceous earth, etc. often is combined with ferric chloride and lime conditioning. Based on European practice, cake solids of 50 percent

TABLE C-8. TYPICAL FILTER PRESS PRODUCTION DATA*

Sludge Type	Suspended Solids (percent)	Conditioning of Dry Solids (percent)		Cake Solids (percent)	Time Cycle (hrs)
Raw Primary	5-10	Ash	100	50	1.5
		$FeCl_3$ Lime	5 10	45	2.0
Raw Primary with less than 50 percent EAS	3-6	Ash	150	50	2.0
		$FeCl_3$ Lime	5 10	45	2.5
Raw Primary with more than 50 percent EAS	1-4	Ash	200	50	2.0
		$FeCl_3$ Lime	6 12	45	2.5
Digested with less than 50 percent EAS	6-10	Ash	100	50	1.5
		$FeCl_3$ Lime	5 10	45	2.0
Digested with more than 50 percent EAS	2-6	Ash	200	50	1.5
		$FeCl_3$ Lime	7.5 15	45	2.5
EAS	Up to 5	Ash	250	50	2.0
		$FeCl_3$ Lime	7.5 15	45	2.5

*Source:EPA Process Design Manual for Sludge Treatment and Disposal.

can be produced using 150 percent to 200 percent ash conditioning. Dewatering to 45 percent solids can be accomplished by conditioning the sludge with 5-6 percent ferric chloride and 10 to 12 percent lime.

SUMMARY

The total quantity of sludge produced by the example primary-secondary wastewater treatment plant is constant, but the quantities of water and of conditioning chemicals are variables dependent on the dewatering method selected. Table C-9 reports the sludge quantities produced.

REFERENCES

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TABLE C-9. SLUDGE QUANTITIES*
(Pounds per Day)+

		Vacuum Filtration		Pressure Filtration	
Item	Thickened	Chemical Conditioning	Polymer Conditioning	Ash Conditioning	Chemical Conditioning
Volatile Solids	1,600	1,600	1,600	1,600	1,600
Inerts	400	400	400	400	400
Total Solids	2,000	2,000	2,000	2,000	2,000
$FeCl_3$	--	52	--	--	120
CaO	--	200	--	--	240
Polymer	--	--	18	--	--
Ash	--	--	--	4,000	--
Subtotal	--	2,252	2,018	6,000	2,360
Water	48,000	9,008	8,072	6,000	2,884
Total Sludge	50,000 (4% Solids)	11,260 (20% Solids)	10,090 (20% Solids)	12,000 (50% Solids)	5,244 (45% Solids)

*Assumes 100% solids capture. Equivalent population is 10,000; sewage flow is 1 mgd (3,800 cu m/day).

+1 lb/day = 0.454 kg/day.

APPENDIX D

REFUSE

REFUSE GENERATION RATES

The following information has been taken from the "Baltimore Region Solid Waste Management Plan", prepared by Roy F. Weston, Inc. for the Baltimore Regional Planning Council. These data have been used because domestic refuse was separated from manufacturing and commercially generated refuse and because the available data included information on a variety of miscellaneous wastes. Domestic waste quantities were correlated with population and with employment-related waste generation in the manufacturing and commercial/institutional sectors.

The study region consisted of the City of Baltimore and the five adjacent counties--Baltimore, Anne Arundel, Carroll, Harford, and Howard. The bulk of the population lives in an urban environment. However, only 16 percent of the region's 1970 population lived in major incorporated urban areas; a corresponding figure for 1960 was 20 percent.

Baltimore City, and its densely populated urban fringe, accounted for the bulk of the urban population. Urban concentrations surround the core city area (portions of Baltimore and Anne Arundel Counties), and there are isolated concentrations around Bel Air and U.S. 40/I-95 in Harford County, the Columbia area in Howard County, the Annapolis area in Anne Arundel County, and the Westminster area in Carroll County.

The area is thus fairly representative of the kind of region where incineration of refuse and sewage sludge needs to be considered, because the availability of landfill disposal sites has been severely restricted by urban sprawl.

In the Baltimore Region, the city and county governments are assuming increasing responsibility, in one form or another, for the collection of domestic solid waste, but basically have left the collection of manufacturing and commercial solid waste to private parties. Anne Arundel County, Baltimore City, and Baltimore and Howard Counties have assumed responsibility for residential solid waste collection. Harford County licenses and regulates private firms which collect solid waste from individual citizens. Only Carroll County still avoids any involvement in residential solid waste collection. While Baltimore City and Baltimore County do collect some employment-related solid waste, it is primarily a private responsibility throughout the Baltimore Region.

In the Baltimore Regional Study wastes were categorized into three groups, according to generating source:

- Domestic waste, which is generated in households.
- Employment-related waste, resulting from the production of goods and services.
- Special waste, which requires special handling.

Both Baltimore City and Baltimore County had records of domestic waste generation. The Department of Sanitation in Baltimore City has scales at both incinerator facilities, and Baltimore County's Sanitation Bureau has maintained weighing records of domestic waste generation since 1967. Per capita domestic waste generation figures for the Region were based upon these data recorded in Baltimore City and Baltimore County.

Similar records did not exist for employment-related waste generation in the Baltimore Region. (Employment-related waste is defined as that resulting from manufacturing, commercial, and institutional activities.) Since the actual generation of employment-related waste is highly dependent on the type and rate of manufacturing, commercial, and institutional activity within a specific region, the refuse generation rates were determined by survey.

The per capita domestic waste generation rates used to develop annual residential waste load projections for Anne Arundel, Carroll, Harford, and Howard Counties were assumed to be the same as those recorded by Baltimore County.

The Baltimore County data disclosed a 1 July 1972 generation rate of 1 kg (2.2 lbs) per capita per day. Data concerning the generation of domestic waste in the City of Baltimore disclosed a generation rate of 1.10 kg (2.42 lbs) per capita per day. This generation rate is at the low end of the National Average.

Domestic waste generation projections were based upon 2 percent, non-compounded annual increase in per capita waste generation. Population estimates (based upon data furnished by the Regional Planning Council) along with annual domestic solid wastes quantities for the years 1970, 1980, and 1990 are presented in Table D-1. National averages included in Table D-1 are from EPA publication "Comparative Estimates of Post Consumer Solid Wastes" by F.A. Smith, EPA/53b SW-148, May 1975.

TABLE D-1. PROJECTED POPULATION AND ANNUAL DOMESTIC REFUSE TONNAGE BALTIMORE REGION--1970 TO 1990

Year	Metric Tons	(Tons) Per Year	Population	Generation Rate#	
1970	788,909	(867,800)	2,070,670	1.05*	2.30+
1980	1,105,820	(1,216,400)	2,435,735	1.25	2.74
1990	1,475,900	(1,623,500)	2,800,800	1.45	3.18

*Weighted average in kg per capita per day: assumes a 2% non-compounded, annual increase.

+Same--on a lb per capita per day basis.

#U.S. National Average for 1971 is 1.06-1.55 kg (2.39-3.48 lb) per capita per day.

The composition of domestic solid waste in the Baltimore region (from the Baltimore Region Plan) is presented in Table D-2. There have been three studies analyzing the composition of domestic waste in Maryland, and these analyses are reported and compared to the average U.S. Refuse Composition.

While domestic waste generation rates may be conveniently correlated with population, any attempt to correlate employment-related waste with population characteristics at the regional level would be very speculative. Plant conditions, access to recycle markets, efficiency and productivity, product mix, and choice of products are but a few of the hard-to-assess factors which determine industrial refuse quantities and account for the remarkable lack of uniformity in regard to waste-handling practices.

For these and other reasons, plus the unavailability of detailed local data, the employment-related wastes were determined from a solid waste survey of the Region. The Standard Industrial Classification (SIC), developed by the Office of Statistical Standards in the Federal Bureau of the Budget, was utilized for the classification of establishments in the Baltimore Region according to their types of activity.

The actual generation rates per employee by SIC code and a detailed description of the manner in which they were used are presented in a separate document entitled "Solid Waste Generation Rates, Baltimore Region". The rates determined by this survey were then applied to the employment in the Baltimore Region to determine the total quantities of wastes generated by census tract.

Solid waste generation rates are not likely to vary as greatly within industrial groups as they do across industrial lines, especially when considering one region of the county. However, waste generation does vary significantly between the manufacturing sector and the commercial/institutional (C/I) sector, both by quantity and type. For the following reasons, the

TABLE D-2. DOMESTIC SOLID WASTE COMPOSITION COMPARISON* -- BALTIMORE REGION

(Percent Total by Weight)

Classification	Baltimore Region	Northern Baltimore County+	Montgomery County	Anne Arundel County	U.S. Average
Garbage	11	11	11	13	8.5
Paper	50	47	53	52	60.0
Glass and Ceramics	10	13	8	16	8.0
Plastic and Rubber	5	5	4	11	3.9
Leather and Linoleum	1	1	1	--	0.4
Wood	4	4	4	--	2.5
Metals	8	8	8	--	8.0
Ashes	1	1	1	2	0.9
Paints and Oils	1	1	1	--	0.3
Forestry	6	6	5	--	6.5
Miscellaneous	3	3	4	6	1.0
Total	100	100	100	100	100

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*Roy F. Weston, Inc. analysis.

+Engineering Evaluation, Solid Waste Transfer-Reduction Facility at Texas, Maryland, Green Associates, Inc., October 1972.

two sectors were presented separately in the Baltimore reports on solid waste management planning for the Baltimore Region:

- The average employee in the manufacturing sector generates more than 7 times the waste generated by the average employee in the C/I sector.
- The estimated current recycle rate is 25.6 percent for the manufacturing sector, and 3.4 percent for the C/I sector.
- A wide variety of wastes is generated in manufacturing operations, while a high proportion of waste in C/I sector is paper.
- The Regional Planning Council estimates that employment will increase between 1970 and 1990 by 9 percent and 41 percent in the manufacturing and C/I sectors respectively.

Table D-3 is a comprehensive survey of waste-generation in the Region. Table D-4 gives a detailed summary of special wastes.

The net employment-related column in Table D-3 includes both the manufacturing and the C/I sectors. For the years in question, the percentage of the net total reported attributable to the C/I sector is 48.6 percent (1970), 55 percent (1980), and 59.3 percent (1990).

The commercial and institutional (C/I) waste-generation category covers a variety of sources. Commercial sources include: shopping centers, restaurants, entertainment facilities, individual retail and wholesale establishments, private-sector offices, motels and hotels, and other non-manufacturing operations. The institutional group consists of hospitals, schools and public buildings, and public services.

The composition of wastes generated from activities in the commercial/institutional sectors is fairly consistent. Although there are seasonal variations in the business activities, these variations do not cause significant corresponding variations in the types of solid wastes generated.

Survey data, which included waste composition breakdowns, disclosed a high percentage of wastepaper generation. For 1970, paper accounted for 65 percent of the C/I waste composition, wood accounted for 13 percent, mixed refuse 13 percent, garbage 8 percent, tires 1 percent, and metals less than 1 percent.

Domestic refuse generation rates can conveniently be reported in terms of per capita population. Manufacturing and C/I waste generation rates should be generated for each region based upon the mix of SIC code enterprises; but we can, for the Baltimore Region, translate the available data into a per capita generation rate.

TABLE D-3. ANNUAL NET WASTE GENERATION -- BALTIMORE REGION
(Tons/year X 1,000)*

Jurisdiction	Year	Net Total+	Gross Total#	Domestic	Net Employment Related
Anne Arundel County	1970	476.6	647.6	119.5	162.8
	1980	706.4	860.3	199.1	235.8
	1990	956.0	10,945.0	297.3	308.7
Baltimore City	1970	1,907.0	3,934.0	400.0	1,065.3
	1980	2,076.9	4,103.9	472.8	1,157.5
	1990	2,246.2	4,273.2	543.1	1,249.8
Baltimore County	1970	1,178.0	1,608.0	249.4	455.4**
	1980	1,475.9	1,862.9	357.3	544.7**
	1990	1,798.8	2,147.1	484.7	634.0**
Carroll County	1970	133.7	993.7	27.7	50.4
	1980	184.3	958.3	43.8	67.3
	1990	235.1	931.7	63.4	80.8
Harford County	1970	201.9	841.9	46.3	80.9
	1980	304.1	880.1	74.0	131.6
	1990	406.9	925.3	107.9	176.2
Howard County	1970	122.7	415.7	24.9	43.2
	1980	299.2	562.9	69.4	104.5
	1990	477.8	715.1	127.1	152.6
Region	1970	4,020.4	8,441.4	867.8	1,858.0
	1980	5,046.8	9,228.4	1,216.4	2,241.4
	1990	6,120.8	10,086.9	1,623.5	2,602.1

* 1 metric ton = 0.907 ton.

+ Total quantity requiring disposal; excludes agricultural wastes, dredgings, dunnage, and floatage debris.

# Does not include waste oil.

** Bethlehem Steel Corp. Sparrows Point Plant figures omitted.

TABLE D-6. ANNUAL NET GENERATION OF SPECIAL WASTES IN THE BALTIMORE REGION (Tons/year X 1,000)*

Jurisdiction	Year	Agricultural Waste+	Net Construction and Demolition#	Dead Animals	Hospital Waste	Junked and Abandoned Vehicles	Leaf Waste	Litter	Recreational Waste	Residential Bulky Waste	Scrap Tires	Sewage Solids**	Street Sweeping	Water Treatment Solids	Waste Oil++
Anne Arundel County	1970	171.0	40.2	0.8	5.5	11.3	0.6	1.9	0.7	25.1	2.8	99.1	6.3	--	991.3
	1980	153.9	55.8	0.8	8.4	16.9	0.9	2.7	1.0	34.8	3.9	137.6	8.7	--	1,294.5
	1990	138.5	71.4	0.9	11.8	23.2	1.1	3.4	1.3	44.6	5.0	176.1	11.2	--	1,597.7
Baltimore City	1970	--	2,273.0	0.7	14.1	35.0	1.9	1.8	1.2	76.3	8.6	25.9	28.1	2.1	12,093.5
	1980	--	2,273.0	0.7	15.3	40.1	1.9	1.8	1.6	75.2	8.3	25.9	27.3	2.5	12,786.6
	1990	--	2,273.0	0.7	16.6	45.9	1.8	1.8	2.2	74.0	8.3	25.9	27.3	2.8	13,479.7
Baltimore County	1970	430.0	53.1	1.6	3.8	29.4	1.3	3.2	1.4	52.3	5.9	302.4	18.8	--	12,076.2
	1980	387.0	63.4	1.7	5.0	43.5	1.6	3.8	1.9	62.5	7.0	361.1	22.4	--	13,933.3
	1990	348.3	73.7	1.8	6.4	62.7	1.8	4.4	2.6	72.7	8.1	419.9	26.0	--	15,790.3
Carroll County	1970	860.0	4.6	2.4	0.3	2.4	0.1	1.4	0.1	5.8	0.7	37.6	0.7	--	191.9
	1980	774.0	6.0	2.4	0.4	3.2	0.2	1.8	0.2	7.7	0.8	49.5	1.0	--	255.0
	1990	696.6	7.5	2.5	0.6	4.0	0.2	2.3	0.2	9.5	1.0	61.5	1.6	--	318.0
Harford County	1970	640.0	12.1	2.2	0.4	3.5	0.2	1.4	0.2	9.7	1.1	42.7	1.2	--	105.0
	1980	576.0	16.1	2.2	0.6	4.7	0.3	1.8	0.3	12.9	1.5	56.8	1.3	--	152.7
	1990	518.4	20.1	2.2	0.9	5.8	0.4	2.3	0.4	16.2	1.8	71.0	1.7	--	200.4
Howard County	1970	293.0	33.3	1.1	--	2.3	0.1	0.8	0.3	5.2	0.6	10.0	0.9	--	82.1
	1980	263.7	77.6	1.2	1.0	3.7	0.3	1.9	0.4	12.1	1.5	23.3	2.3	--	193.7
	1990	237.3	121.8	1.3	1.7	8.3	0.5	2.9	0.5	19.1	2.1	36.5	3.4	--	305.3
Region	1970	2,394.0	2,416.3	8.8	24.1	83.9	4.2	10.5	3.9	174.4	19.7	517.7	56.0	2.1	25,540.0
	1980	2,154.6	4,908.2	9.0	30.7	112.1	5.2	13.8	5.4	205.2	23.0	654.2	63.0	2.5	29,836.2
	1990	1,939.1	4,594.5	9.4	38.0	149.9	5.8	17.1	7.2	236.1	26.3	790.9	71.2	2.8	34,132.3

* 1 Metric ton = 0.907 ton.
+ Projections assume a 10 percent decrease in waste quantity per decade.
# Includes 2,000,000 tons of dredgings and 27,000 tons of dunnage and flotage debris for Baltimore City.
** Excludes septic tank sludge.
++ Gross total in thousand gallons per year (3.79 liters = 1 gal).

The RFP has stipulated the sewage treatment plant (STP) sizes of 1, 10 and 100 mgd, which at 100 gpd per capita correspond to 10,000, 100,000, and 1,000,000 people. Using 1980 as the base year and considering only domestic refuse at 1.25 kg (2.74 lb) per capita per day, we can determine the approximate size of a refuse incinerator (a further assumption is 24 hours per day operation for 6 days per week operation and 50 weeks per year). Thus, the incinerator size equivalent to a 3,785 cu m/day (1 mgd) STP is 15.5 metric ton/day (17 tpd), for a 37,850 cu m/day (10 mgd) STP the equivalent incinerator is 155 metric ton/day (170 tpd), and for a 378,500 cu m/day (100 mgd) STP the equivalent refuse incinerator is 1,550 metric ton/day (1,700 tpd).

The foregoing information may be used as base line data where the sewage treatment plant handles largely domestic sewage and the refuse incinerator handles largely domestic refuse.

While the net employment-related refuse quantities were developed on the basis of specific industries and enterprises and their specific waste generation rates, these data may be converted to an equivalent generation rate per capita of 2.24 kg/C/D (4.92 lb/C/D)--1970, 2.29 kg/C/D (5.04 lb/C/D)--1980, and 2.31 kg/C/D (5.09 lb/C/D)--1990. The commercial and institutional per capita waste rates are thus 1.09 (2.39) for 1970, 1.26 (2.77) for 1980, and 1.37 (3.02) for 1990, all data reported in kg (pounds) per capita per day.

For purposes of the co-incineration study, the domestic refuse generation rates derived from the Baltimore area report will be used as a base line during the feasibility study of selected techniques. Since the refuse generation rates attributable to manufacturing or to the commercial/institutional sector are highly dependent upon the actual business structure of the community, these data will be incorporated into the feasibility study only when necessary to provide additional heat to allow burning the sewage solids generated by an equivalent population.

Refuse Characteristics

The quantity of refuse generated in a region is important, but so is the quality of the refuse. The quality (energy/mass as received) is highly variable and dependent upon a number of factors:

- Geographic location
- Season of the year
- Climatic conditions
- Collection practice
- Industrial, commercial, residential sources.

Refuse characteristics are expected to change with time, thus reflecting the changes in our consumption of disposable items. Municipal refuse incineration is therefore a unique process in that the feed stock changes from year to year, month to month, day to day, and probably from hour to hour.

To illustrate the variability, Table D-5 has been abstracted from a review paper presented at an A.I.Ch.F. Meeting (E.M. Smith, "Municipal Incinerator Emissions--Current Knowledge," 72nd A.I.Ch.E. Meeting, St. Louis, Missouri, May, 1972); Office of Solid Waste Management Programs data are also included.

TABLE D-5. MUNICIPAL REFUSE COMPOSITION

Category	ADL Percent by Weight	OSWMP Percent by Weight
Food Wastes	0.8 to 34.6	2.2 to 30.0
Yard Wastes	1.6 to 33.3	0.0 to 26.0
Miscellaneous	0.2 to 23.6	----
Glass, Ceramics	2.0 to 17.9	0.9 to 24.6
Metal	4.6 to 14.5	4.2 to 15.9
Paper Products	17.5 to 61.8	21.6 to 76.6
Leather, Rubber, Plastics	1.0 to 5.8	1.0 to 6.6
Textiles	0.4 to 4.8	0.2 to 13.4
Wood	0.3 to 22.4	0.0 to 11.5
Oil, Paint, Chemicals, etc.	0.8 to 12.0	----
Ash, Rock, Dirt	----	0.0 to 32.2

The total incombustibles are highly variable, as can be seen from the Table D-5, and another variable is the moisture content. The moisture content reported in Table D-6 shows a range of 18.1 to 48.1 percent moisture.

Perhaps the best example of the extreme variability in refuse composition is to examine the "yard wastes" category in Table D-5, where, according to OSWMP data, the percentage varies from 0.0 to 26.0 Both of these percentages are reported for the same incinerator test series during July and separated in time by only two days.

A recent review of solid waste heating values was published in 1974 (A.C.W. Eggen and R. Kraatz, "Relative Value of Fuels Derived from Solid Wastes," Proceedings of 1974 National Incinerator Conference, ASME, N.Y., N.Y., pages 19-32, May, 1974). The authors review the work of previous investigators who have reported upon the averages reported range from 19,400 to 20,900 J/g (8,340 to 9,000 Btu/lb) of combustibles. The authors then suggest a heating value of 10,200 J/g (4,400 Btu/lb) of refuse as received, with moisture content of 0.28 kg of water per kg of refuse and inerts of 0.22 per kg of refuse. They also report the average kg of combustible per kg of refuse as received ranging from 0.50 to 9.5 percent.

TABLE D-6. REFUSE MOISTURE CONTENT

Incinerator	Location	Month	Moisture as Sampled Percent by Weight
C	Southern	July-August	21.5
			27.4
			32.2
			24.8
			26.5 Average
D	Midwest	October	20.7 Average
E	Southern	December	24.2
			19.8
			18.5
			18.1
			20.2 Average
F	Southern	December	21.1
			20.2
			21.8
			21.0 Average
G	Southern	February	25.6
			28.9
			28.5
			29.6
			28.2 Average
H	Middle Atlantic	January	25.3
			48.1
			32.0
			25.8
			27.0
			31.6 Average

(Reference: OSWMP open file test reports)

While average heating values are useful, it is also important to understand the effect of variations in refuse composition as it affects both the heating value and the inerts content (water and residue). Figure D-1 relates refuse heating value to the percent combustible, or (inversely) to the percent inert content of the MMR. This figure was based on a series of test reports prepared by the Office of Solid Waste Management Programs (OSWMP) of the Federal EPA. The data from these reports indicate that the heating value of fresh refuse moisture- and ash-free ranges from 14,000 to 18,000 kg-cal/kg (7,920 to 9,800 Btu/lb, average 16,000 kg-cal/kg (8,960 Btu/lb). The centerline, therefore, represents the average based on the OSWMP reports, and the upper and lower lines represent the expected variation.

Available data indicate that the average combustible content of MMR is approximately 50 percent; in Figure D-1, 50 percent combustible corresponds to a refuse heating value of 8,100 kg-cal/kg (4,500 Btu/lb) as received. The 8,100 kg-cal/kg value compares favorably with the average proposed by Eggen and Kraatz and is based on data available to all practitioners of the art. An additional reason for basing the heating value on the OSWMP data is that the information was derived using a methodology that was reasonably consistent and which has been formalized in a testing manual for solid waste incinerators (W.C. Achinger, and J.J. Giar, "Testing Manual for Solid Waste Incinerators," open file report (SW-3ts), U.S. Environmental Protection Agency, 1973).

Baseline data will, therefore, be 8,100 kg-cal/kg (4,500 Btu/lb) on an as-received basis of 50 percent combustible material and 50 percent inert material; the inerts will be composed of 44 percent residue and 56 percent moisture.

We also need to know the ultimate analysis of the combustible fraction of the refuse. Using the OSWMP data, we have derived the following average values:

Element	Percent
Carbon	49.4
Hydrogen	5.2
Oxygen	43.6
Nitrogen	0.9
Sulfur	0.3
Chlorine	0.6
	100.0

This ultimate analysis is on a dry ash-free basis.

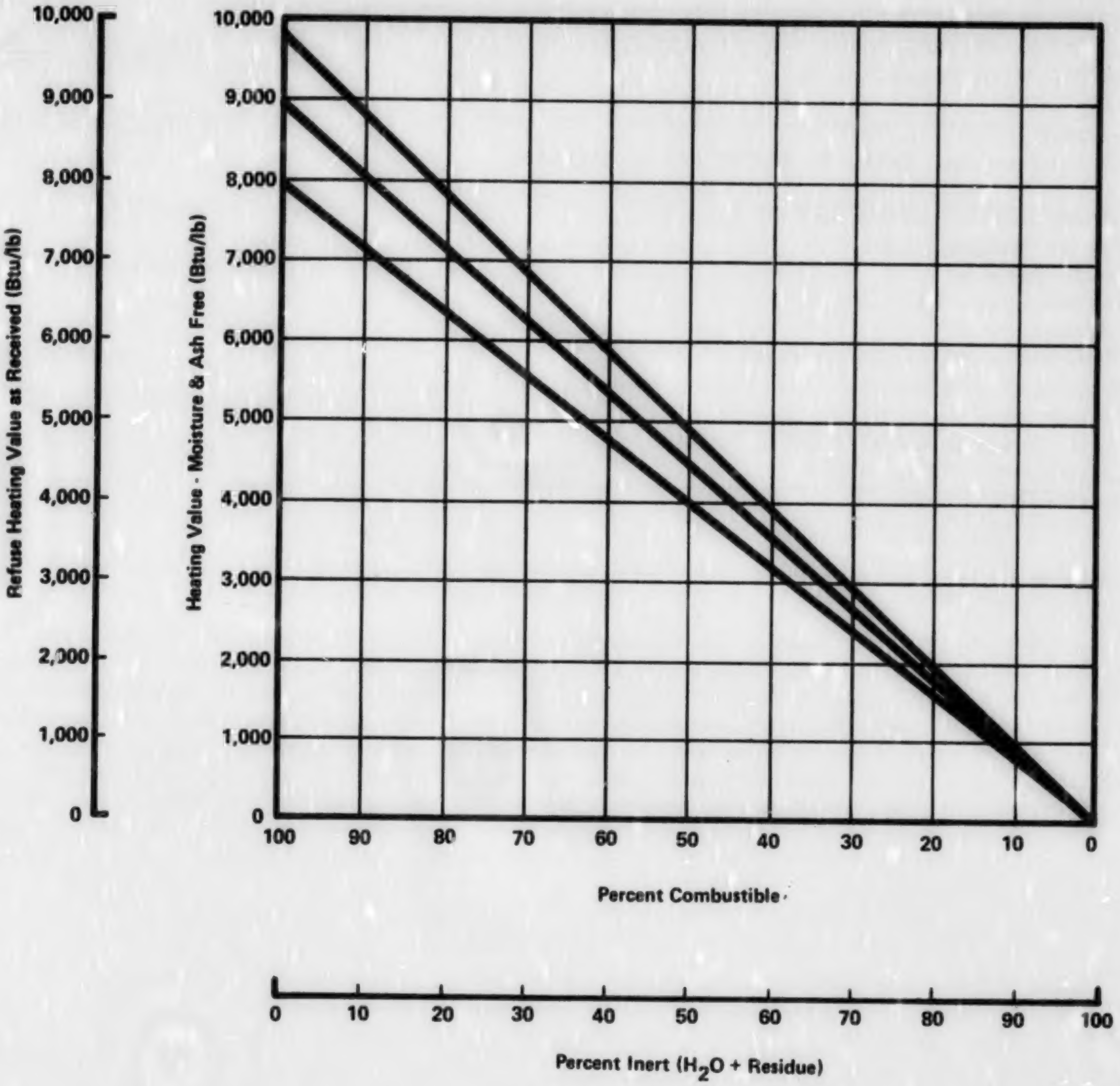

Figure D-1. Refuse Heating Value as Received (EPA-OSWMP Open File Reports).